WATER QUALITY AND AQUATIC COMMUNITIES OF UPLAND WETLANDS, CUMBERLAND ISLAND NATIONAL SEASHORE, GEORGIA, APRIL 1999 TO JULY 2000

By Elizabeth A. Frick, M. Brian Gregory, Daniel L. Calhoun, and Evelyn H. Hopkins

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ACRONYMS AND ABBREVIATIONS

ACRONYMS

CCC	**C**riterion **C**ontinuous **C**oncentration
GGS	**G**eorgia **G**eologic **S**urvey
KBMP	**K**ings **B**ay **M**onitoring **P**roject
MCL	**M**aximum **C**ontaminant **L**evel
MRL	**M**inimum **R**eporting **L**evel
NPS	**N**ational **P**ark **S**ervice
NWI	**N**ational **W**etlands **I**nventory
NWIS	**N**ational **W**ater **I**nformation **S**ystem
RASA	**R**egional **A**quifer **S**ystem **A**nalysis
U.S.	**U**nited **S**tates
USEPA	**U**.**S**. **E**nvironmental **P**rotection **A**gency
USGS	**U.S**. **G**eological **S**urvey

ABBREVIATIONS

ANC	acid neutralizing capacity	mg/L	milligram per liter
As	arsenic	mi^2	square mile
Br	bromide	µS/cm	microsiemen per centimeter
Ca	calcium	µg/L	microgram per liter
$CaCO_3$	calcium carbonate	mm	millimeter
Cd	cadmium	Mn	manganese
Cl	chloride	N	nitrogen
col/100 mL	colonies per 100 milliliters	Na	sodium
Cr	chromium	Ni	nickel
Cu	copper	NO_3	nitrate
° C	degrees Celsius	NTU	nephelometric turbidity units
DO	dissolved oxygen	P	phosphorus
F	fluoride	Pb	lead
Fe	iron	PO_4	orthophosphorus
ft	foot	SC	specific conductance
HCO_3	bicarbonate	SiO_2	silica dioxide
Hg	mercury	SO_4	sulfate
K	potassium	TDS	total dissolved solids
Mg	magnesium	Zn	zinc
Mgal/d	million gallons per day		

VERTICAL DATUM

Sea Level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called “Sea Level Datum of 1929.”

HORIZONTAL DATUM

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

WATER QUALITY AND AQUATIC COMMUNITIES OF UPLAND WETLANDS, CUMBERLAND ISLAND NATIONAL SEASHORE, GEORGIA, APRIL 1999 TO JULY 20003

By Elizabeth A. Frick, M. Brian Gregory, Daniel L. Calhoun, and Evelyn H. Hopkins

ABSTRACT

Cumberland Island is the southernmost and largest barrier island along the coast of Georgia. The island contains about 2,500 acres of freshwater wetlands that are located in a variety of physical settings, have a wide range of hydroperiods, and are influenced to varying degrees by surface and ground water, rainwater, and seawater. In 1999–2000, the U.S. Geological Survey, in cooperation with the National Park Service, conducted a water-quality study of Cumberland Island National Seashore to document and interpret the quality of a representative subset of surface- and ground-water resources for management of the seashore's natural resources. As part of this study, historical ground-water, surface-water, and ecological studies conducted on Cumberland Island also were summarized.

Surface-water samples from six wetland areas located in the upland area of Cumberland Island were collected quarterly from April 1999 to March 2000 and analyzed for major ions, nutrients, trace elements, and field water-quality constituents including specific conductance, pH, temperature, dissolved oxygen, alkalinity, tannin and lignin, and turbidity. In addition, water temperature and specific conductance were recorded continuously from two wetland areas located near the mean high-tide mark on the Atlantic Ocean beaches from April 1999 to July 2000. Fish and invertebrate communities from six wetlands were sampled during April and December 1999. The microbial quality of the near-shore Atlantic Ocean was assessed in seawater samples collected for 5 consecutive days in April 1999 at five beaches near campgrounds where most recreational water contact occurs.

Ground-water samples were collected from the Upper Floridan aquifer in April 1999 and from the surficial aquifer in April 2000 at 11 permanent wells and 4 temporary wells (drive points), and were analyzed for major ions, nutrients, trace elements, and field water-quality constituents (conductivity, pH, temperature, dissolved oxygen, and alkalinity). Fecal-coliform bacteria concentrations were measured, but not detected, in samples collected from two domestic water-supply wells. During the 12-month period from April 1999 to March 2000 when water-quality and aquatic-community samples were collected, rainfall was 12.93 inches below the 30-year average rainfall.

Constituent concentrations were highly variable among the different wetlands during the study period. Rainfall and tidal surges associated with tropical storms and hurricanes substantially influenced water quantity and quality, particularly in wetland areas directly influenced by tidal surges. Although surface waters on Cumberland Island are not used as sources of drinking water, exceedances of U.S. Environmental Protection Agency primary and secondary standards for drinking water were noted for comparative purposes. A nitrate concentration of 12 milligrams per liter in one sample from Whitney outflow was the only exceedance of a maximum contaminant level. Secondary standards were exceeded in 26 surface-water samples for the following constituents: pH (10 exceedances), chloride (8), sulfate (5), total dissolved solids (4), iron (2), fluoride (1), and manganese (1). The total-dissolved-solids concentrations and the relative abundance of major ions in surface-water samples collected from wetlands on Cumberland Island provide some insight into potential

sources of water and influences on water quality. Major-ion chemistries of water samples from Whitney Lake, Willow Pond, and South End Pond 3 were sodium-chloride dominated, indicating direct influence from rainwater, salt aerosol, or inundation of marine waters. The remaining wetlands sampled had low total-dissolved-solids concentrations and mixed major-ion chemistries—North Cut Pond 2A was magnesium–sodium–chloride–sulfate dominated and Lake Retta and the two beach outflows were sodium–calcium–bicarbonate–chloride dominated. The higher percent calcium and bicarbonate in some wetlands suggests a greater influence from ground-water discharge.

Aquatic insects whose life cycles and behavioral adaptations allow them to inhabit wetlands characterized by a range of hydroperiods, water-quality, and habitat conditions dominated aquatic-invertebrate communities in upland wetlands of Cumberland Island. In foredune areas adjacent to the Atlantic Ocean, estuarine wetlands contained marine invertebrates such as shrimp and crabs, along with aquatic insects typically associated with freshwater wetlands. The richest invertebrate communities were present in floating and emergent aquatic vegetation of Whitney Lake. Fish communities of Cumberland Island wetlands were typically dominated by species that tolerate highly variable water-quality conditions and bear their young live, attributes that allow these species to quickly populate water bodies with short or variable hydroperiods. The most diverse wetland areas in terms of fish communities were the beach outflows. Species inhabiting beach outflows consisted of fishes able to tolerate fresh- to brackish-water conditions and species typically associated with marine waters.

Cumberland Island is within the cone of depression associated with large withdrawals for industrial use that have occurred since 1939 in Fernandina Beach, Fla. and in St Marys, Ga. In 1999, the potentiometric surface of the Upper Floridan aquifer ranged from a maximum of about 40 feet above sea level at the northern most well measured to a minimum of about 18 feet above sea level near the southern end of Cumberland Island. Limited ground-water-level measurements in wells on Cumberland Island indicate seasonal and annual variability in water levels; however, water-level data are not sufficient to make conclusions about trends in water levels on Cumberland Island during the last decade.

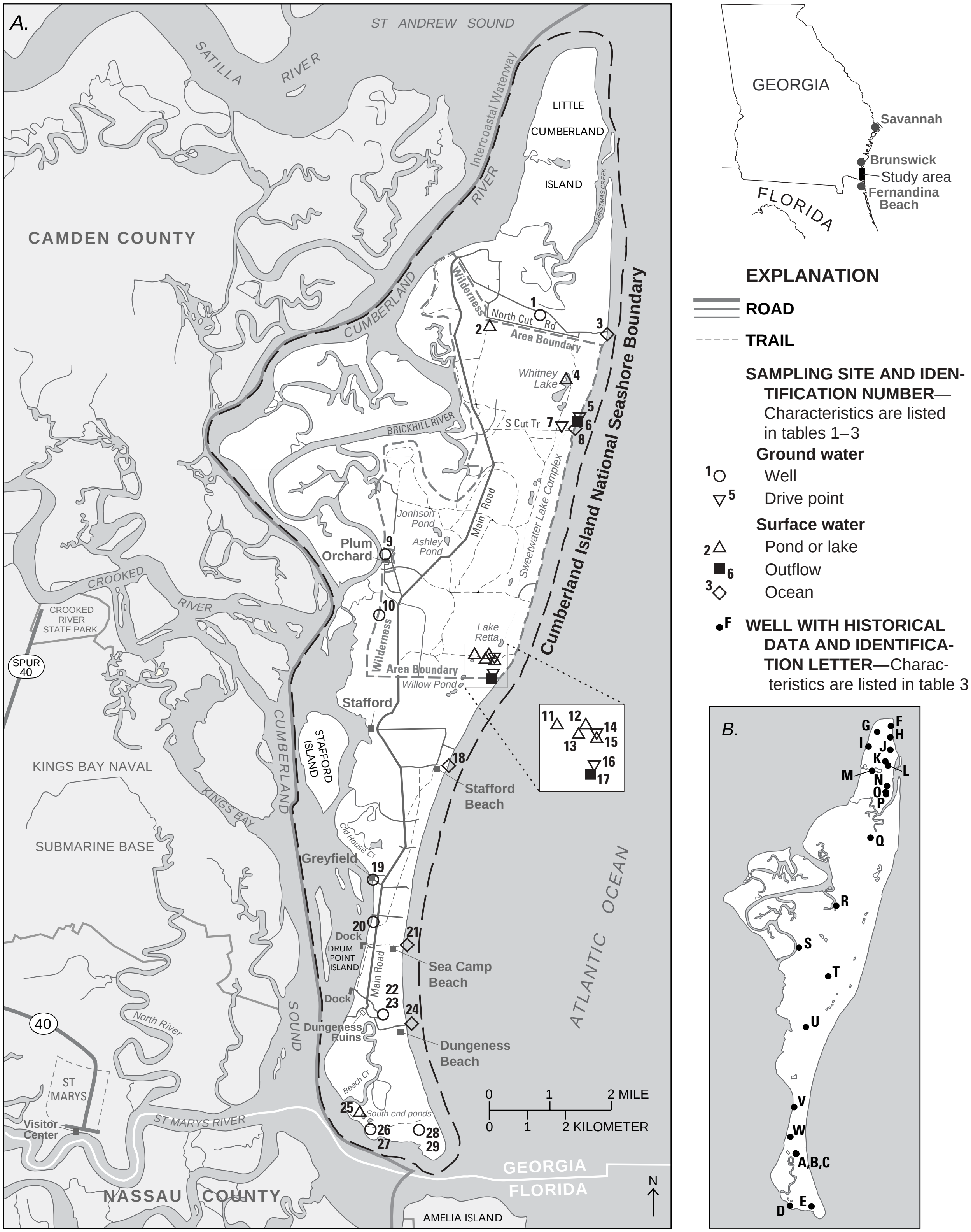
U.S. Environmental Protection Agency maximum contaminant levels and secondary standards for drinking water were not exceeded in five domestic water-supply wells open to the Upper Floridan aquifer that were sampled in 1999. Chloride concentrations ranging from about 31 to 37 mg/L and limited evidence related to the depth and location of the freshwater/saltwater interface indicate that saltwater intrusion is currently not a problem in the Upper Floridan aquifer on Cumberland Island. Saltwater intrusion into the shallow surficial aquifer at the southern end of Cumberland Island is the primary reason for common exceedances of the secondary standards for chloride, sulfate, total dissolved solids, and manganese.

INTRODUCTION

Cumberland Island is the southernmost and largest barrier island on the coast of Georgia (fig. 1). Established as a National Seashore in 1972, Cumberland Island has 17.5 miles of undeveloped Atlantic Ocean beaches and is a biologically and topographically diverse barrier island. Cumberland Island is well known for its abundant shore birds, sea turtles, dune fields, vast estuaries, and salt marshes, as well as its historic structures that echo a rich pattern of human use and settlement. Less well known are Cumberland Island’s extensive freshwater wetlands and abundant supply of potable ground water, which in turn have contributed to the diverse ecology and pattern of human settlement and land use on the island.

Surface- and ground-water resources have played an important role in human habitation and resource development on Cumberland Island. The first known human use of the island and its water resources was by Native Americans around 600 B.C. (Milanich, 1970) and the Spanish and English in 1532 (Bense, 1994; Steve Moore, National Park Service, oral commun., 2001). In the late 1700's, several prominent families from the northeastern United States (U.S.) settled on Cumberland Island and established working plantations where sea-island cotton, cattle, and rice were raised, and timber was harvested for shipbuilding. The Thomas Carnegie family eventually purchased a substantial portion of the island, building five mansions and summer homes. In 1887, in order to obtain freshwater for domestic uses and decorative fountains, the Carnegie family constructed the first deep wells to tap what is now known as the Upper Floridan aquifer on Cumberland Island (McCallie, 1898).

Cumberland Island was a popular resort at the turn of the century; however, its popularity declined in the years preceding the Great Depression. In 1959, after several failed attempts to make the island profitable and with



Base modified from National Park Service, Cumberland Island National Seashore, 1998

Figure 1. Location of Cumberland Island National Seashore, Georgia; (*A*) sampling sites, April 1999 to July 2000; and (*B*) wells with historical data.

mining companies eager to lease tracts to remove minerals contained in the island’s interior sands, the remaining members of the Carnegie family set up the Cumberland Island Company and began considering the sale of their portion of Cumberland Island to the National Park Service (NPS). In 1972, about 70 percent of the Carnegie land on Cumberland Island was transferred to the NPS and became Cumberland Island National Seashore. Approximately 24 to 36 year-round and part-time residents, including NPS and Greyfield Inn staff, and private landowners live on Cumberland Island and Little Cumberland Island (Andrew Ferguson, National Park Service, oral commun., 2001). Private land on Cumberland Island and Little Cumberland includes 5 fee-simple land holdings where individuals own the land and 21 retained-rights properties where individuals and the next generation have the right to live on the land. Retained-rights properties will ultimately revert to NPS land (Andrew Ferguson, National Park Service, oral commun., 2001). In 2000, more than 44,000 visitors visited or camped at Cumberland Island National Seashore (National Park Service, written commun., 2000).

The NPS has been conducting basic resource inventories in several parks nationwide through its Service-Wide Inventorying and Monitoring Program. The primary objectives of the program are to ensure that every national park containing natural resources has at least a nominal inventory of its natural resources, and that those data are available in a data-management system consistent with park management needs. Presently, data to support park management needs at Cumberland Island National Seashore lack critical information—especially data pertinent to the surface- and ground-water resources and quality, the ecology of the island's freshwater wetlands, and the sanitary quality of the recreational waters of the near-shore Atlantic Ocean. In 1999–2000, the U.S. Geological Survey (USGS), in cooperation with the NPS, conducted a surface- and ground-water study of Cumberland Island National Seashore to provide data for management of the island’s natural resources.

Purpose and Scope

This report provides a water-resource inventory of Cumberland Island as part of the NPS Service-Wide Inventorying and Monitoring Program. Historical information on water resources and current influences and controlling factors of wetland hydroperiods, surface-water quality, aquatic communities, and ground-water levels and quality are also included. The purpose of this study was to document and interpret the quality of a representative subset of key surface- and ground-water resources essential to the cultural, historical, and natural-resources management themes of Cumberland Island National Seashore and to make this information available to Cumberland Island National Seashore management personnel, NPS water-resource personnel, and other scientists.

As part of this study, surface-water-level, surface-water-quality, and aquatic invertebrate and fish-community data were collected from representative wetlands on Cumberland Island; enterococci data were collected from 5 Atlantic Ocean beaches; and ground-water-quality data were collected from 11 existing and 4 drive-point wells. All data-collection activities were completed from April 1999 through July 2000.

In addition, historical ground-water, surface-water, and ecological studies conducted on Cumberland Island are summarized. Existing data for Cumberland Island related to the National Wetlands Inventory, well construction, ground-water withdrawal, ground-water levels, precipitation, tides, and wave height were compiled and are presented to help explain current water-quality conditions and aquatic communities.

Surface Water

Cumberland Island has the largest and most diverse system of wetlands on any of Georgia’s barrier islands (Hillestad and others, 1975). In addition to more than 16,500 acres of salt marshes, mud flats, and tidal creeks, there are more than 2,500 acres of freshwater wetlands that range from permanent and semi-permanent ponds to seasonal wetland areas including emergent, scrub/shrub, and forested palustrine areas (fig. 2). Many of the wetlands on Cumberland Island, as well as those on other large barrier islands of the southeastern and Gulf coasts of the U.S., are associated geomorphically with dune and swale topography (Odum and Harvey, 1988). These interdunal wetlands are present where (1) dune and swale topography has persisted since at least the middle to late Holocene (2,000 to 5,000 years before present), (2) a lens of fresh ground water intersects the bottoms of the swales, and (3) extensive flooding by seawater is infrequent (Odum and Harvey, 1988). Many of these freshwater wetlands are in swales between dunes and result from trapping rainwater in the narrow areas between dunes (Hillestad and others, 1975, p. 58) or from ground-water discharge into closed or nearly closed surface depressions (fig. 3; Hillestad and others, 1975, p. 70-71). Other major freshwater wetlands on

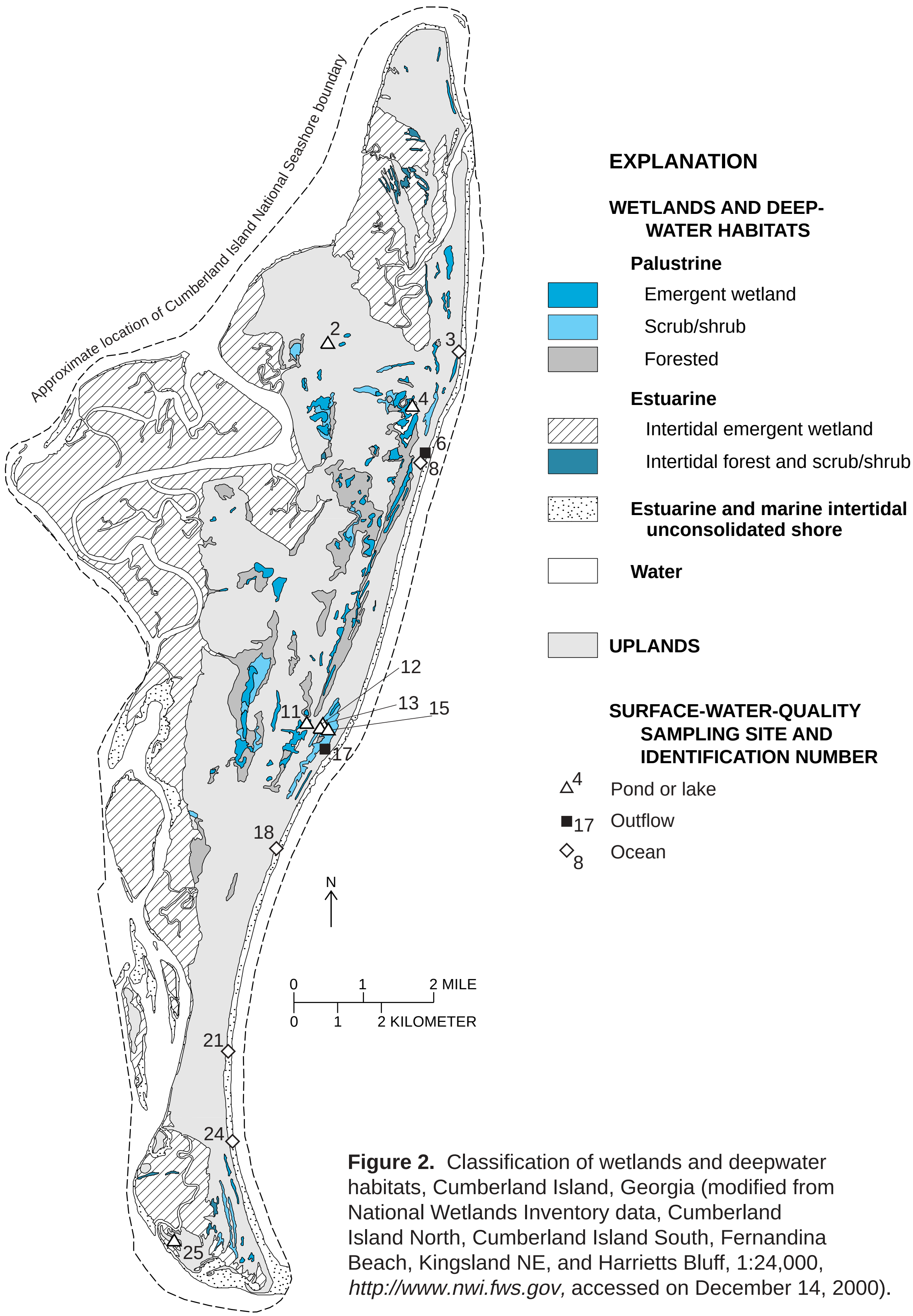


Figure 2. Classification of wetlands and deepwater habitats, Cumberland Island, Georgia (modified from National Wetlands Inventory data, Cumberland Island North, Cumberland Island South, Fernandina Beach, Kingsland NE, and Harrietts Bluff, 1:24,000, *http://www.nwi.fws.gov,* accessed on December 14, 2000).

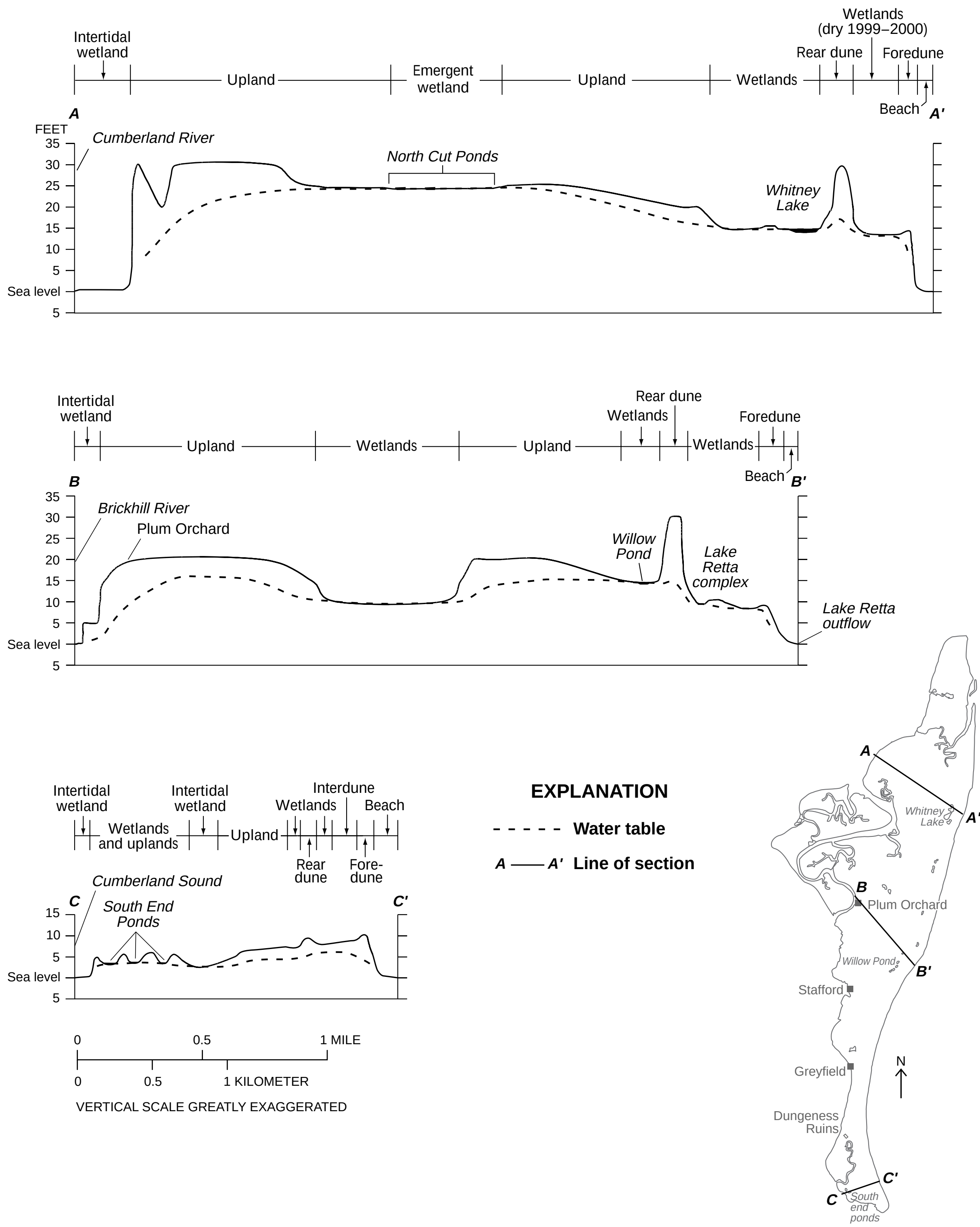


Figure 3. Generalized cross sections showing geomorphic settings and hydrologic features, Cumberland Island, Georgia.

Cumberland Island include those associated with low-lying areas in interior portions of the island and areas adjacent to estuaries on the northern and southern portions of the island (fig. 2). Intertidal emergent wetlands on the western side of the island are the most extensive wetlands on Cumberland Island; however, these wetlands are brackish and were not included as part of this study.

Freshwater wetlands increase biodiversity on barrier islands by providing habitat for animals such as frogs, salamanders, water snakes, turtles, and aquatic mammals—all of which are largely absent from barrier islands lacking freshwater habitats (Bellis, 1995). Barrier-island freshwater wetlands commonly provide the only dependable source of water for upland fauna such as whitetail deer and feral horses and hogs. In addition, wetlands provide habitat for aquatic plants, aquatic invertebrates, and fishes, as well as nesting, feeding, and roosting areas for wading and shore birds. Several Federally listed animals, including Brown Pelicans (endangered), Wood Storks (endangered) and the American Alligator (delisted in 1987), are known to use freshwater aquatic habitats on Cumberland Island for portions of their life cycle (Hillestad and others, 1975).

Freshwater wetlands on Cumberland Island occur in a range of physical settings, with varying degrees of permanence and connectivity to seawater. Odum and Harvey (1988) indicated that freshwater interdunal wetlands are rare and fragile resources, occur on a number of barrier islands in the southeastern U.S., and are sufficiently varied and limited in total area to warrant preservation and management. The integrity and viability of interdunal wetlands and ponds are dependent on protection of the dune and swale systems from erosion and direct alteration and protection of the barrier island's surficial aquifer. Plant communities, wildlife, and aquatic animals are closely linked to the island’s wetlands, which provide habitats to some threatened or endangered organisms.

Surface-water features and wetlands on Cumberland Island represent a broad range of hydrologic and biologic conditions that may be related to different successional stages. Water-level fluctuations, fire, and changes in salinity due to seawater inundation and to evaporation are perturbations that affect wetland extent, characteristics, and biologic conditions (Hillestad and others, 1975, p. 50-51). These somewhat regular perturbations help prevent or slow successional processes that lead to wetlands infilling and disappearing (Hillestad and others, 1975).

In addition to the ecological importance of the freshwater resources on Cumberland Island, the near-shore Atlantic Ocean is important as a recreational resource to island visitors. Most water-contact recreation on Cumberland Island occurs during summer months at beach areas near campgrounds and beach access trails. Although relatively low, the potential exists for microbial contamination from wildlife and feral animals on Cumberland Island and from areas north of the island. The southward-flowing longshore current in the Atlantic Ocean transports water southward from other Georgia barrier islands, the Satilla River, and from St. Andrew Sound (fig. 1). Jekyll Island is the barrier island north of Cumberland Island and includes the City of Jekyll Island—a resort community that receives about 1.3 million visitors per year (Cindy Thomas, Jekyll Island Welcome Center, oral commun., 2001). The wastewater-treatment plant on Jekyll Island is permitted to discharge a maximum of 1.0 Mgal/d of treated effluent more than 4 miles north of Cumberland Island into Jekyll Creek, which flows into St. Andrew Sound (J.L. Fanning, U.S. Geological Survey, written commun., 2001).

Ground Water

The surficial and Upper Floridan aquifers (fig. 4) on Cumberland Island are the primary sources of drinking water for residents, park employees, and visitors. The deep-lying and confined Upper Floridan aquifer is important regionally for industrial and municipal uses and supplies drinking water for almost all domestic wells on Cumberland Island. The shallower Pliocene and late Miocene deposits that comprise most of the water-bearing zones of the surficial aquifer also have been used, primarily by the NPS, as a drinking-water resource on the island. Unconfined portions of the surficial aquifer are important for sustaining freshwater wetland ecosystems on Cumberland Island. The confining units and aquifers between the surficial aquifer and the Upper Floridan aquifer were not evaluated (fig. 4) because no water-level or water-quality data are available from wells open to this interval.

The surficial aquifer consists of unconsolidated sands, clays, and gravels that are recharged locally. Depths to water measured since 1990 range from about 3.5 to 14 ft below land surface in the surficial aquifer on Cumberland Island. Water levels in the surficial aquifer vary seasonally and respond to local changes in recharge and discharge. Recharge to the aquifer is primarily by infiltration of rainfall and seepage from wetlands. Recharge also may occur through upward leakage in areas where the

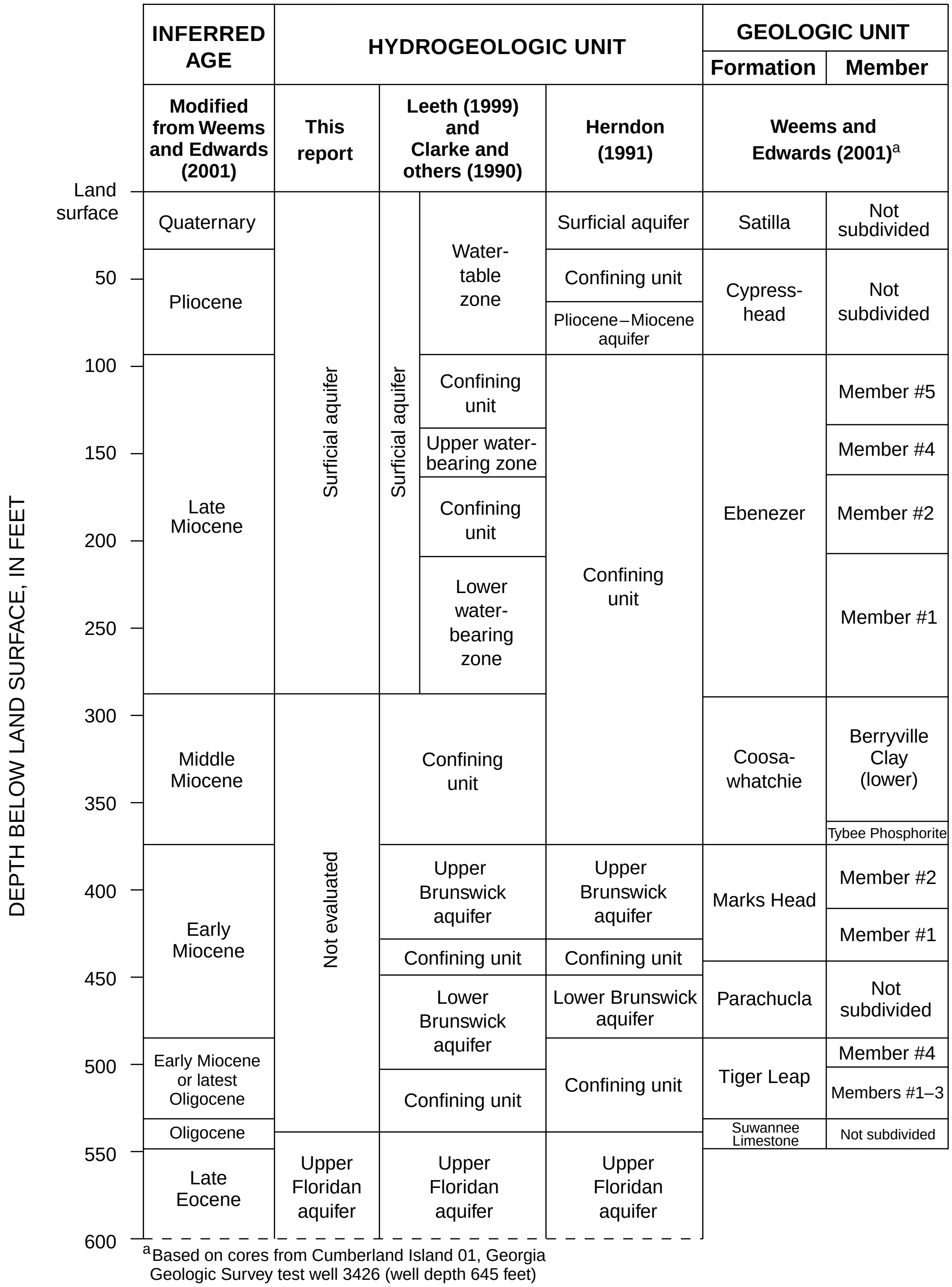


Figure 4. Generalized hydrogeology and geology, Cumberland Island, Georgia.

hydrologic potential in underlying confined aquifers is higher than in the surficial aquifer. Water is discharged from the surficial aquifer by evapotranspiration and flow to wetlands, coastal areas, and locally to wells. Several wells in NPS campgrounds, generally less than 90-ft deep, and wells developed primarily for drinking water purposes near visitor's facilities, about 65- to 235-ft deep, obtain water from Pliocene and late-Miocene water-bearing zones (McLemore and others, 1981, section 5, p. 2). Wells screened in the surficial aquifer are more susceptible to saltwater intrusion and contamination from activities on Cumberland Island than are deeper wells that are drilled through confining units and into the Upper Floridan aquifer. On the southern end of Cumberland Island, Wilson (1990), Herndon (1991), and Mack (1994) subdivided the surficial aquifer and described flow directions and saltwater intrusion within various layers of the surficial aquifer; however, the hydrogeology, hydraulic properties, and water quality in the surficial aquifer for the northern two-thirds of Cumberland Island are largely unknown.

The Upper Floridian aquifer is recharged shoreward from the island, is used extensively as a source of industrial and public water supply, and has been subject to long-term declines in water levels and in some areas to saltwater intrusion or encroachment (Spechler, 1994). The Upper Floridian aquifer consists of limestone and dolomite and is about 600- to 700-ft thick on Cumberland Island (Miller, 1986, plate 28). The top of the Upper Floridian aquifer is more than 500 ft below land surface on Cumberland Island (Miller, 1986, plate 26), and the aquifer is confined. For wells open to the Upper Floridan aquifer and with water-level or water-quality data in this report, the deepest known well depth is 784 ft. Depths to water measured since 1966 range from about 0.3 to 40 ft above land surface in wells open to the Upper Floridan aquifer on Cumberland Island. The altitude of the potentiometric surface of the Upper Floridan aquifer has ranged from about 13 to 52 ft above sea level based on water-level measurements since 1966. The first well open to the Upper Floridan aquifer on Cumberland Island was installed in 1887 near the Dungeness home on the southern end of the island. When first drilled, the well flowed at an estimated 0.8 Mgal/d from a depth of 680 ft, with an estimated head of 51 ft above land surface (McCallie, 1898). McLemore and others (1981) inventoried 48 wells on Cumberland Island, which did not include all wells on private lands, and reported that 15 of the 48 wells inventoried were believed to tap the Upper Floridan aquifer.

Water withdrawn from the Upper Floridan aquifer beneath Cumberland Island generally contains a sufficient concentration of hydrogen sulfide to produce an odor and affect the taste. According to Hillestad and others (1975, p. 49), most domestic water-supply wells on Cumberland Island are connected to oxidation vats to facilitate the dissipation of hydrogen sulfide. Sulfate in ground water is derived from dissolution of gypsum, anhydrite (calcium sulfate), iron sulfides (such as pyrite), other sulfur compounds in aquifer materials, and potentially from mixing with seawater (Brown, 1984, p. 46; Stringfield, 1966, p. 140). In northeastern Florida, gypsite dissolution occurs (Katz, 1992, p. 32-33) and upconing of mineralized water along fault zones may account for higher concentrations of SO_4 (Sprinkle, 1989). Based on SO_4 concentrations in water samples collected from wells open to the Upper Floridan aquifer, gypsite dissolution also is likely to occur in the Cumberland Island area.

Ground-water withdrawal associated with coastal development in the Fernandina Beach, Fla.,–St Marys, Ga., area (located in Nassau County, Fla., and Camden County, Ga., respectively) (fig. 1); increased from less than 0.5 Mgal/d in 1938, to 33 Mgal/d in 1940, to 75 Mgal/d in 1957, to 85 Mgal/d in 1970, to 105 Mgal/d in 1977 (fig. 5). Industrial water use (primarily pulp and paper mills) accounted for about 68 to 94 percent of ground-water withdrawals in Nassau County, Fla., from 1965 to 1999 (R.L. Marella, U.S. Geological Survey, written commun., 2002) and for about 77 to 87 percent of ground-water withdrawals in Camden County, Ga., from 1985 to 2000 (*http://water.usgs.gov/watuse*, accessed on March 2002; J.L. Fanning, U.S. Geological Survey, written commun., 2002). In the late 1970’s and during the 1980’s, water withdrawals by pulp and paper mills decreased, partly because of increased recirculation of process water (Marella, 1995, p. 19; Fanning, 1999, p. 9). Ground-water withdrawal in Nassau and Camden Counties decreased from 105 Mgal/d in 1977 to 91 Mgal/d in 1980 (Brown, 1984, p. 19), and has fluctuated between about 81 and 90 Mgal/d from 1985 to 2000 (fig. 5). The State of Georgia has established an Interim Strategy for Managing Saltwater Contamination in the Upper Floridan aquifer that caps ground-water use in the Savannah (fig. 1) and Brunswick (about 12 miles north-northwest of Cumberland Island) areas at 1997 rates, and encourages water conservation and reduced water use in areas along the Georgia coastline (Barlow, 2000). However, this cap on ground-water use does not extend as far south as Camden County, Ga. (L.E. Jones, U.S. Geological Survey, oral commun., 2002).

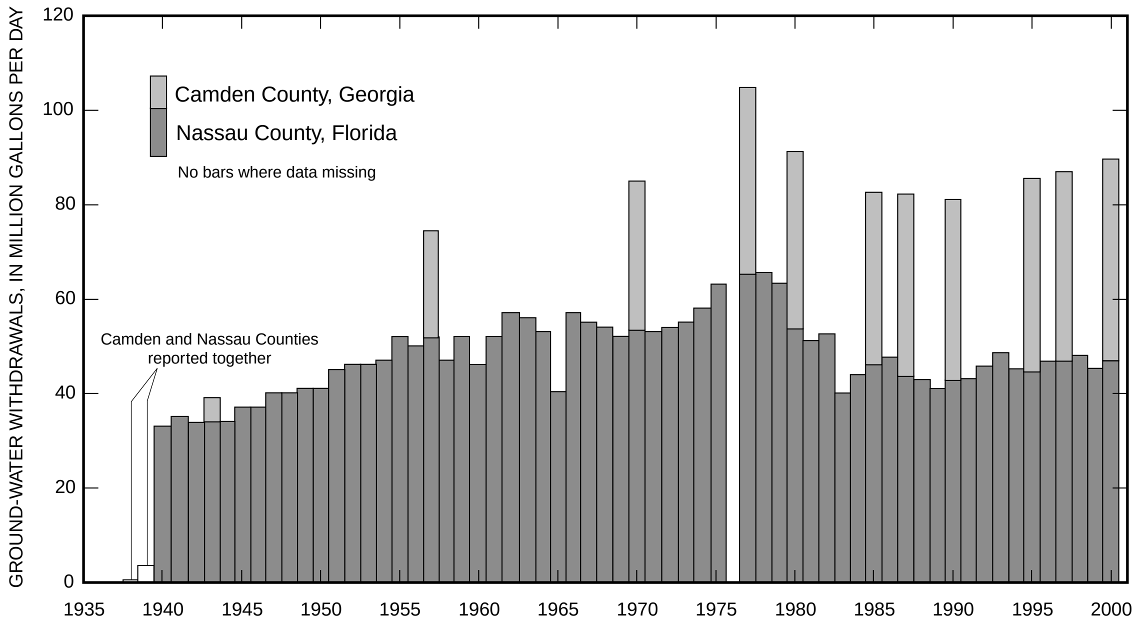


Figure 5. Estimated ground-water withdrawal in Nassau County, Florida, and Camden County, Georgia, 1938–2000. [Data sources: Stringfield, 1966; Fairchild and Bently, 1977; Brown, 1984; Trent and others, 1990; Marella, 1995; Fanning, 1999; *http://water.usgs.gov/watuse*, accessed on March 18, 2002; J.L. Fanning, U.S. Geological Survey, written commun., 2002; and R.L. Marella, U.S. Geological Survey, written commun., 2002.]

Near the Georgia coast, where the Upper Floridan aquifer is confined, water levels respond primarily to pumping (Clarke and others, 1990; Cressler and others, 2001, p. 7). Ground-water withdrawal associated with coastal development in southeast Georgia and northeast Florida have caused declines in the potentiometric surface of the Upper Floridan aquifer such that cones of depression have developed around the nearby cities of Brunswick, Ga., St Marys, Ga., and Fernandina Beach, Fla. (fig. 1). Cumberland Island is within the cone of depression associated with large withdrawals for industrial use that have occurred since 1939 in Fernandina Beach, Fla. and soon thereafter in St Marys, Ga. (Warren, 1944, p. 18-a; Hillestad and others, 1975; Bush and Johnston, 1988, plate 5; Spechler, 1994; Peck and others, 1999). Declines in the potentiometric surface are important because they indicate changes in the long-term balance between recharge and discharge. Over time, declines in the potentiometric surface can shift the location of the natural saltwater-freshwater interface shoreward, potentially causing seawater to intrude the fresh-water aquifers.

In the 1880’s, prior to development, the potentiometric surface of the Upper Floridan aquifer at Cumberland Island was about 60 to 65 ft above land surface (Warren, 1944, p. 26; Stringfield, 1966, p. 119 and 121; Johnston and others, 1980). In Nassau County, Fla., ground-water withdrawal increased from less than 0.5 Mgal/d in 1938 to 33 Mgal/d in 1940 (fig. 5). As a result of this increased pumpage, a cone of depression centered near Fernandina Beach, Fla., had developed by 1942, and the estimated potentiometric surface had decreased to between 40 and 50 ft above land surface for most of Cumberland Island (Warren, 1944, p. 18-a). From 1961 to 2000, the potentiometric surface of the Upper Floridan aquifer had declined to between 30 and 40 ft above sea level at the northern end of Cumberland Island to near sea level at the southern end of the island (Stringfield, 1966, p. 120; U.S. Geological Survey, 1978, p.7; Brown, 1984, p. 30-39; Clarke and others, 1987, p.147; Peck, 1991; Peck and others, 1999; Bradner and Knowles, 1999; Knowles, 2000; 2001). By 1994, in an area about 2 miles south of Cumberland Island near the center of pumping at Fernandina Beach, Fla., the potentiometric surface had declined 120 ft from an estimated predevelopment potentiometric surface of 60 to 70 ft above land surface (Spechler, 1994, p. 19-21; Johnston and others, 1980).

Previous Investigations

Surface-water-quality data collection on Cumberland Island has been limited; however, surface-water quality in southeastern barrier island freshwater wetlands has been described as highly variable (Bellis, 1995; Oskarsson, 1991)—ranging from high-salinity water bodies with direct connection to the ocean or sounds, to freshwater ponds and sloughs completely isolated from seawater. The only previous synoptic study (Hillestad and others, 1975) of the water resources of Cumberland Island summarized the land-use history and provided descriptions of geology, soils, surface-water resources, flora, and fauna. Hillestad and others (1975) made numerous recommendations regarding management of wildlife habitat and water resources for the NPS to incorporate into management plans for Cumberland Island.

Kozel (1991) collected monthly water-quality samples from three ponds—a freshwater (pond 1), a low-salinity (pond 3), and a high-salinity pond (pond 2)—on the south end of Cumberland Island from April 1988 through May 1990. Kozel (1991) reported the following ranges for physical and water-quality constituents: pond depths, 0 to 549 mm; water temperatures, 10 to 40 ^{o}C; salinity, 0 to 40,000 parts per thousand; pH, 4.0 to 9.4, and PO_4, 0.2 to 4.8 mg/L. Kozel (1991) tentatively concluded that strong seasonal changes in water quality appeared to reflect precipitation events and the cycle of spring tides. Kozel (1991) also documented the presence or absence of fishes in these ponds by collecting monthly samples. Five species were collected during Kozel’s study; higher numbers of fishes were collected during the fall, higher Shannon Diversity Index values were observed during the spring, and the greatest Simpson Dominance values were observed during the summer. Kozel (1991) stated that for ponds on the south end of Cumberland Island, the cyclic nature of filling and drying was the result of a combination of spring tides, precipitation, and evaporation; and hypothesized that these cycles were the driving forces behind observed changes in the fish fauna.

Lambert (1992) investigated long-term vegetation trends in and near Whitney Lake by using aerial photographs taken over a 46-year period to document changes and to predict successional and geomorphological changes for Whitney Lake.

Indicator-bacteria data for ground water, surface water, or seawater on or near Cumberland Island were not found in published literature. No studies have been published investigating the possible relation between indicator-bacteria concentrations in areas directly north of Cumberland Island and levels in the near-shore recreational waters of Cumberland Island.

In the 1980’s, several reports published by the USGS described the results of regional analyses of the Floridan aquifer system in Florida, and in parts of Georgia, South Carolina, and Alabama. Johnston and Bush (1988) provided a summary of the Regional Aquifer-System Analysis (RASA) findings for the Floridan aquifer system, and Miller (1986) provided the hydrogeologic framework for the Floridan aquifer system. Krause and Randolph (1989) used a three-dimensional finite-difference model to simulate ground-water flow in the Floridan aquifer system under predevelopment (about 1880) and 1980 conditions in a 30,000-square-mile area that includes Cumberland Island. Based on ground-water-quality data collected from 1950 to 1982, Sprinkle (1989) described the natural geochemistry, hydrochemical facies, relation between water chemistry and the ground-water flow system, and geochemical changes induced by pumping from the Floridan aquifer system and land development in recharge areas. Katz (1992) incorporated many of the ground-water-quality analyses used by Sprinkle (1989), as well as data from the Florida Ground-Water Quality Monitoring Network Program, to map concentrations of major ions and hydrochemical facies within the Upper Floridan aquifer in Florida. Although none of the 601 control wells used by Sprinkle (1989, p. I22, plate 1) and none of the 787 wells used by Katz (1992, p. 9-10) were on Cumberland Island, typical concentrations of major ions and some minor constituents within the Upper Floridan aquifer can be estimated for Cumberland Island based on these regional maps.

Extensive lists of investigations on the geology, hydrology, and geologic structure of the Upper Floridan aquifer in southeastern coastal areas including Georgia were compiled by Krause and others (1984), Miller (1986), Krause and Randolph (1989), and Clarke and others (1990). McLemore and others (1981) described the geology, stratigraphy, hydrology, landforms and natural vegetation, land use, historical changes in the mean high-water shoreline, hazards, and vertebrate paleontology of Cumberland Island. McLemore and others (1981, section 5, p. 11) reported average major-ion concentrations in water from the principal artesian aquifer (now more commonly referred to as the Upper Floridan aquifer) and the Pliocene-Miocene aquifer (referred to as the surficial aquifer in this report). However, information describing locations of wells sampled, dates when samples were collected, or the number of samples collected were not included.

Maps of Cl concentrations in the Upper Floridan aquifer for coastal Georgia, including Cumberland Island, have been published for November 1984 (Clarke and others, 1990, p. 46-47), October-November 1988 (Joiner and others, 1989, p. 161), and May 1990 (Cressler, 1991, p. 1; Milby and others, 1991, p. 137-138). Chloride concentrations in the Upper Floridan aquifer ranged from 28 to 41 mg/L during 1984 to 1993, based on 27 samples collected from 12 wells on Cumberland Island (data are available online at *http://water.usgs.gov/ga/nwis/nwis*, accessed on February 27, 2002).

Based on limited water-quality data collected in September 1980 from seven wells open to the Upper Floridan on Cumberland Island, Brown (1984, p. 59) reported the following ranges for water-quality constituents: specific conductance (SC), 710 to 750 µS/cm; Cl, 31 to 38 mg/L; and SO_4, 160 to 190 mg/L.

In the late 1980's, the U.S. Navy deepened the Kings Bay Trident Submarine ship channel, near St Marys, Ga. Several studies investigated potential changes to water resources on the southern end of Cumberland Island as a result of channel dredging in Cumberland Sound (Herndon, 1991; Wilson, 1990; Mack 1994; American Society of Civil Engineers, 1991). Herndon (1991) and Herndon and Cofer-Shabica (1991) described the geologic and hydrologic framework, including estimates of hydrologic properties, aquifer interaction, and the potential for seawater intrusion into the Pliocence-Miocene aquifer from Cumberland Sound. Wilson (1990) and Wilson and others (1991) described the hydrogeochemistry of the surficial, Pliocene-Miocene, and Miocene sand aquifers. Field water-quality constituents and major-ion data were collected in July and December 1989 from 11 wells at 3 sites with nested wells near the south end of Cumberland Island. Mack (1994) concluded that saltwater intrusion into the surficial aquifer likely originates from the natural submarine outcrop off the southern end of Cumberland Island that predated the deepening of the Kings Bay Trident Submarine ship channel. Mack (1994) also concluded that the principal ground-water-flow direction in the surficial aquifer on the western side of southern Cumberland Island is toward the west and likely inhibits saltwater intrusion from Cumberland Sound.

In addition to some of the potentiometric surface maps of the Upper Floridan aquifer cited in the Ground Water section of the Introduction, the USGS has published potentiometric surface maps for May and September for most years from 1974 through 2000 for northeastern Fla., (St. Johns River Water Management District) and extending as far north as Cumberland Island (*http://fl.water.usgs.gov/Pubs_products/ByRegion.html#Northern*, accessed on March 7, 2002). The May maps are intended to represent water levels near the end of the dry season and the September maps are intended to represent water levels near the end of the wet season in northeastern Florida (Leel Knowles, Jr., U.S. Geological Survey, oral commun., 2002). At least nine potentiometric surface maps of the Upper Floridan aquifer in Georgia from 1976 to 1990 were included in annual ground-water data reports (U.S. Geological Survey, 1978; Clarke and others, 1979, 1985, 1986, 1987; Matthews and others, 1980, 1981; Stiles and Matthews, 1983; Milby and others, 1991).

Acknowledgments

Appreciation is extended to Daniel J. Hippe (USGS) for the project proposal and initial study design and to Jennifer Bjork (former Resource Manager, Cumberland Island National Seashore) along with other members of the NPS staff who provided assistance transporting gear and personnel to and from the island, as well as logistical support for conducting fieldwork on the island. Appreciation is also extended to private landowners who granted permission for the USGS to collect ground-water samples from their domestic wells.

METHODS OF INVESTIGATION

Data-collection methods included standard techniques used to assess water quality in surface and ground water and are documented in Wilde and others (1999a, b) and Shelton (1994). Specific methods and other relevant information pertaining to sample collection and processing used in this study are presented in the following sections.

Surface Water

Surface-water sites were selected to represent the major types of wetlands on Cumberland Island (table 1). To aid in classifying sites by wetland types, the National Wetlands Inventory (NWI) 1:24,000-scale digital data (U.S. Fish & Wildlife Service, National Wetlands Inventory digital data,

Table 1. Site characteristics and summary of surface-water-quality and biological data collected, Cumberland Island, April 1999 to March 2000
[—, data not collected or information not known]

Location number (fig. 1)	Site-identification number	Site name	Latitude	Longitude	Altitude above sea level (feet)	Water quality[1/]				Invertebrates and fishes[2/]		Water temperature	Specific conductance	Enterococci				
						1999			2000	1999		April 1999 to July 2000		April 1999				
						Apr	Oct	Dec	Mar	Apr	Dec			26	27	28	29	30
						Palustrine wetlands												
2	305443081261101	North Cut Pond 2A	30°54'43"	81°26'11"	23	1	1	1	Dry	1	1	—	—	—	—	—	—	—
4	305356081245701	Whitney Lake	30°53'56"	81°24'57"	13	1	1	1	1	1	1	—	—	—	—	—	—	—
11	304958081262801	Willow Pond	30°49'58"	81°26'28"	14	—	—	—	1	—	—	—	—	—	—	—	—	—
12	304957081261401	Lake Retta complex at foot bridge on Willow Pond Trail	30°49'57"	81°26'14"	7.5	—	—	1	—	—	—	—	—	—	—	—	—	—
13	304953081261701	Lake Retta complex 420 feet south of foot bridge	30°49'53"	81°26'17"	7.5	1	—	—	—	—	—	—	—	—	—	—	—	—
15	304953081260901	Lake Retta	30°49'53"	81°26'09"	7.5	1	1	1	1	1	1	—	—	—	—	—	—	—
25	304327081282201	South End Pond 3	30°43'27"	81°28'22"	2.5	1	1	1	1	1	1	—	—	—	—	—	—	—
						Estuarine wetlands												
6	305319081244601	Whitney outflow	30°53'19"	81°24'46"	7	1	1	1	1	1	1	[3/]3,717	[3/]3,717	—	—	—	—	—
17	304937081261201	Lake Retta outflow	30°49'37"	81°26'12"	7.5	1	1	1	1	1	1	[4/]9,151	[5/]8,572	—	—	—	—	—
						Marine[6/]												
3	305436081241701	North Cut Road Beach	30°54'36"	81°24'17"	0	—	—	—	—	—	—	—	—	0	2	2	2	2
8	305313081244901	South Cut Trail Beach	30°53'13"	81°24'49"	0	—	—	—	—	—	—	—	—	2	2	2	2	2
18	304823081265401	Stafford Beach	30°48'23"	81°26'54"	0	—	—	—	—	—	—	—	—	2	2	2	2	2
21	304551081273501	Sea Camp Beach	30°45'51"	81°27'35"	0	—	—	—	—	—	—	—	—	1	2	2	2	2
24	304443081273101	Dungeness Beach	30°44'43"	81°27'31"	0	—	—	—	—	—	—	—	—	2	1	2	2	2
Total number of samples collected or observations recorded						7	6	7	6	6	6	12,868	12,289	7	9	10	10	10

[1/]Field water-quality constituents, turbidity, nutrients, major ions, tannin and lignin, and trace elements.
[2/]Qualitative assessment of presence or absence.
[3/]Data recorded hourly from April 29–30, 1999; June 30–Sept. 20, 1999; and Oct. 5–Dec. 15, 1999.
[4/]Data recorded hourly from April 29–Sept. 14, 1999; Sept 15, 1999; Sept. 17–21, 1999; Sept. 23–Oct. 13, 1999; and Dec. 15, 1999–July 21, 2000.
[5/]Data recorded hourly from April 29–Sept. 14, 1999; and Dec. 15, 1999–July 21, 2000.
[6/]Atlantic Ocean samples were collected at two water depths of about 1.5 and 3 feet at each site.

http://www.nwi.fws.gov, accessed on December 14, 2000) for five quadrangles (Cumberland Island North, Cumberland Island South, Fernandina Beach, Harriett's Bluff, and Kingsland North East) were compiled for the Cumberland Island National Seashore. Wetland classifications for sampled surface-water sites were assigned by digitally overlaying sampling site locations onto the NWI coverage using a Geographic Information System. Wetland classifications for sampling sites located on or near the border between two different wetland types or not delineated by the NWI were classified based on field observations and data collected during this study. Water-chemistry modifiers developed by NWI (table 2 and Glossary) and used to indicate water types present in wetlands were assigned based on field observations and the results of water-quality data collected during this study. Wetland terminology and classifications presented in this report conform to Cowardin and others (1979).

Staff gages were installed and set to arbitrary datums at six surface-water sites. Gage height (relative surface-water level) was measured at staff gages during each sampling trip. Staff gages were left in place so that water levels during future water-resource studies can be compared with water levels recorded during this study (Appendix A). Staff gages provide the opportunity to develop long-term records of water-level fluctuations in several wetland environments on the island.

Surface-Water Quality

Surface-water-quality samples were collected from a subset of water bodies on Cumberland Island (table 1). One to four surface-water samples were collected from April 1999 through March 2000 from North Cut Pond 2A, Whitney Lake, Whitney outflow, Lake Retta complex, Lake Retta outflow, Willow Pond, and South End Pond 3 (fig. 1, table 1). Tidal creeks on the western side of Cumberland Island were not sampled during this study.

All samples were collected and processed according to USGS protocols (Wilde and others, 1999a, b; Shelton, 1994). Dissolved oxygen (DO), pH, water temperature, and SC were measured *in situ* using multiprobe field meters (Hydrolab) that were calibrated daily. Turbidities and tannin and lignin were analyzed using a portable field spectrophotometer (Hach, model DR/2010). Tannin and lignin were analyzed using the Tyrosine method (Hach Company, 1997, method 8193; and Thurman, 1985). Field alkalinities were determined using a digital titrator (Hach, model 16900) and the incremental titration method (Wilde and Radke, 1998, p. alk-13 to alk-27). Water samples collected for major ions, trace elements, and nutrients were preserved and analyzed at USGS laboratories in Atlanta, Ga., or Ocala, Fla. (Fishman, 1993). Quality-control and quality-assurance samples were collected during each sampling trip, and included field replicates and inorganic blank water samples analyzed in conjunction with environmental samples.

Water temperature and SC sensors (USGS-Hydrologic Instrumentation Facility sensors and Campbell Scientific, Inc. CR-10 data recorders) recorded data once per hour when sensors were operating correctly from April 1999 to July 2000 at the Whitney outflow and the Lake Retta outflow. Because of the relatively harsh near-shore environment, the remoteness of these sites, and the limited number of site visits, data-collection rates were about 31 percent for the Whitney outflow sensor and 75 percent for the Lake Retta outflow sensor. Data collected from these instruments were used to assess changes in water temperature and SC of the outflows to the beach that may indicate changes in the relative contribution of fresh and seawater near the instruments. Data collected from these instruments were compared to data collected from nearby oceanic and climatic stations to discern major influences on SC in the outflows.

Water samples from the near-shore Atlantic Ocean were collected to determine enterococci concentrations at five recreational beaches near roads or trail access points on Cumberland Island (fig. 1). Once per day during a 5-day period from April 26-30, 1999, dip samples were collected from two depths in the wave zone—where the Atlantic Ocean was about 1.5 and 3 ft deep. Samples were chilled while transported to a field laboratory. Maximum sample hold times were less than 3 hours. Samples were processed using membrane filtration (Myers and Wilde, 1999); enterococci concentrations are expressed as col/100 mL of water. Quality-control and quality-assurance samples for enterococci included field-replicate and blank samples processed in conjunction with environmental samples.

Aquatic Communities

Aquatic invertebrates and fishes were collected at six of the surface-water sites in April and December 1999. Similar sampling efforts were expended while collecting fishes and invertebrates in each wetland during spring and fall sampling to discern seasonal differences between sampling dates and among sites. Except for collections made at

Table 2. Classification of wetlands and deepwater habitats sampled March 1999 to July 2000, Cumberland Island

[NWI, National Wetlands Inventory; —, information unknown or not applicable]

Location number (fig. 1)	Water bodies sampled March 1999 to July 2000	Description of wetlands and deepwater habitats: System	Subsystem[2/]	Class	Subclass	Water-regime modifier	Water-chemistry modifier	Geomorphic setting	Similar wetland areas[1/]
				Palustrine wetlands					
2	North Cut Pond 2A	Palustrine	—	emergent	persistent	seasonally flooded	freshwater	upland depression	unnamed and isolated wetlands in upland areas on north end of Island
4	Whitney Lake	Palustrine	—	emergent, floating bed, and unconsolidated bottom	persistent	permanently flooded to seasonally flooded	freshwater	rear dune	unique in size and water regime
11	Willow Pond	Palustrine	—	unconsolidated bottom and emergent	persistent	semipermanently to seasonally flooded	freshwater	upland depression, backdune	similar to Whitney Lake although shallower and less extensive
12, 13, 15	Lake Retta complex	Palustrine	—	scrub-shrub, emergent, and forested	broad-leaved deciduous and evergreen	seasonally flooded	freshwater	interdune	unnamed wetland area northwest of Willow Pond (shown on cross section B-B′, fig. 3) and to a lesser extent Sweetwater Lake complex and unnamed wetland areas on south end of Island
25	South End Pond 3	Palustrine	—	unconsolidated bottom	—	permanently flooded to tidal	polyhaline to euhaline	upland depression (estuarine influence)	pond complex in vicinity of sampled water body on south end of Island
				Estuarine wetlands					
6, 17	Whitney outflow, Lake Retta outflow	Estuarine	intertidal[3/]	emergent[3/]	persistent	irregularly flooded[3/]	mixohaline	foredune	unique in setting; similar to Red Bridge Outflow[4/] and McIntosh Bridge Outflows[4/] on western side of Island
				Marine					
3, 8, 18, 21, 24	North Cut Road, South Cut Trail, Stafford, Sea Camp, and Dungeness Beaches	Marine	intertidal to subtidal	unknown bottom and unconsolidated shore	—	subtidal to regularly flooded	euhaline	beach	entire eastern shore of Cumberland Island

[1/]From Cowardin and others, 1979; and U.S. Fish & Wildlife Service, National Wetlands Inventory digital data, *http://www.nwi.fws.gov*, accessed on 12/14/2000.

[2/]No subsystems for palustrine wetland systems.

[3/]Based on field observations and Hillestad and others (1975). Different from E1UBL classification for Lake Retta outflow on National Wetlands Inventory maps; Whitney outflow not included in National Wetlands Inventory.

[4/]Named in Hillestad and others (1975).

Whitney Lake, all habitat types present at each wetland were sampled.

Semiquantitative (relative-abundance) samples of aquatic-invertebrate communities were collected using a timed method of sweeping and kicking with D-frame nets (210-micron mesh). Effort expended ranged from 1 to 2 person hours per site, but varied depending on the amount of available habitat at each water body. At each water body, sampling efforts were identical for April and December. Large and rare invertebrates were separated from the main body of samples in the field and preserved in 10 percent formalin. Both components of each invertebrate sample were returned to the USGS Georgia District Office in Atlanta, Ga., where smaller invertebrates were removed under magnification from the main body of the sample. Identifications were made by the USGS National Water-Quality Laboratory Biology Group, Denver, Colo.

Multiple seine hauls were conducted using a 10-ft by 6-ft seine (1/8-inch mesh) to collect fish from each water body. Seining was continued until at least three consecutive seine hauls yielded no new species of fish. At Whitney Lake, seining was used to sample only the shallow, near-shore areas—the deeper, open-water habitat was not sampled. Voucher specimens were preserved in 10 percent formalin and verified by the staff ecologist in the USGS Georgia District Office. All fish and invertebrate specimens retained as part of this study were given to Cumberland Island National Seashore for archival purposes.

Ground-Water Quality

Ground-water-quality samples were collected in April 1999 and March 2000 from the two major aquifers underlying Cumberland Island—the surficial aquifer and the Upper Floridan aquifer. Sampling locations included five domestic water-supply wells distributed throughout the island that are open to the Upper Floridan aquifer, six shallow monitoring wells at the south end of the Island that are screened in the surficial aquifer, and four temporary drive-point wells in Holocene deposits near the Lake Retta and Whitney outflows (table 3, fig. 1). The four drive-point wells were sampled to investigate the similarity between shallow ground-water quality and surface-water quality in nearby wetlands. Ground-water-quality samples were collected according to USGS protocols (Koterba and others, 1995; Lapham and others, 1995) and were analyzed for DO, pH, temperature, SC, tannin and lignin, turbidity, alkalinity, major ions, nutrients, and trace elements according to USGS protocols (Fishman, 1993; Fishman and Friedman, 1989; Wilde and Radtke, 1998; Wilde and others, 1999a, b; Thurman, 1985). Water samples collected from two of five domestic water-supply wells sampled also were analyzed for fecal-coliform bacteria (Myers and Wilde, 1999). All hydrologic and water-quality data collected as part of this study are stored in the USGS National Water Information System (NWIS) data bases and are listed in appendices (Appendixes A, B, and C) to this report.

SURFACE WATER

The extent of freshwater wetlands on Cumberland Island varies widely based on a number of factors including climatic conditions, ground-water levels, recent storm surges, and fires. In 1975, Cumberland Island was reported to have about 1,000 acres containing shallow standing water for at least 6 months of the year and another 1,000 acres that might be expected to flood after heavy rains (Hillestad and others, 1975, p. 50-51). Based on photographs from March 1983 and February 1984, the U.S. Fish and Wildlife National Wetland Inventory classified about 2,500 acres (18 percent) of upland areas on Cumberland Island as wetlands (U.S. Fish & Wildlife Service, National Wetlands Inventory digital data, *http://www.nwi.fws.gov*, accessed on December 14, 2000). Wetland areas of Cumberland Island National Seashore consist of palustrine, estuarine, and marine wetlands. The majority of wetlands in the upland portion of the Island consist of palustrine forest (56.9 percent), palustrine emergent (25.9 percent), palustrine scrub/shrub 15.0 percent), palustrine lake (1.0 percent), and palustrine aquatic bed (1.0 percent). Other wetland types present within the boundaries of Cumberland Island National Seashore include estuarine salt marshes and tidal creeks located primarily on the western side of the island and on beaches along the eastern side.

Surface-water data-collection activities for this study were conducted on Cumberland Island from April 1999 to July 2000, which was a period of drier than normal conditions (fig. 6). Antecedent rainfall conditions were 13.31 inches below normal for the 12-month period prior to sample collection. During the 12-month period from April 1999 through March 2000 when water-quality samples were collected for this study, rainfall was 12.93 inches below the 30-year average rainfall. During the 16-month period from April 1999 through July 2000 when temperature and SC data were collected from the outflows, there was a 19.33-inch rainfall deficit.

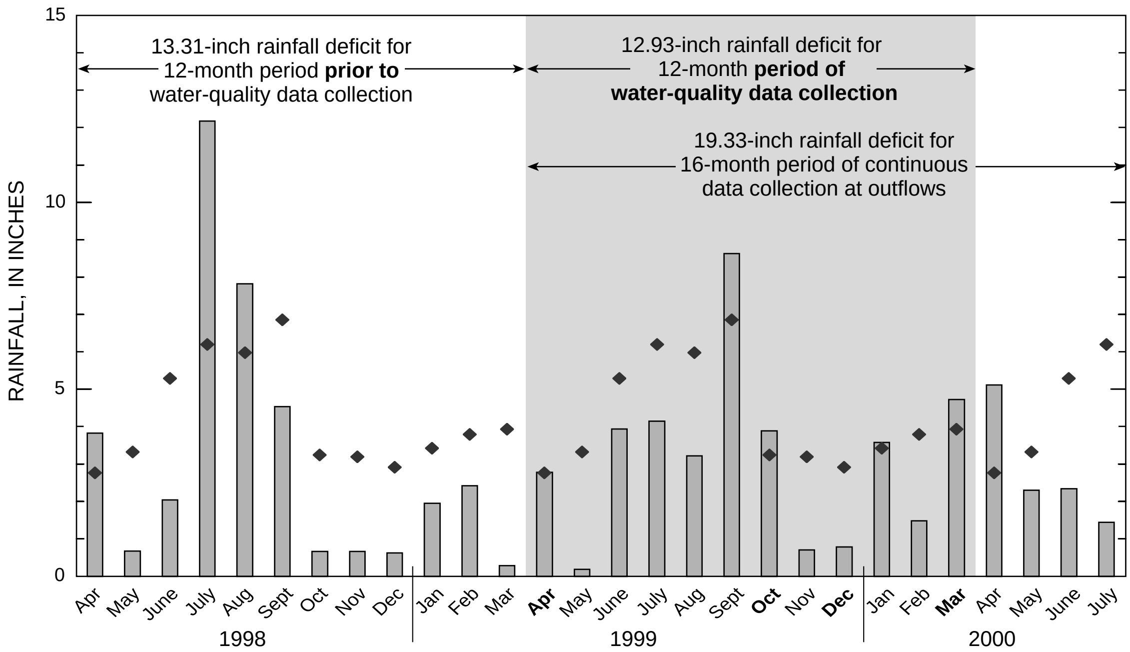


Figure 6. Monthly rainfall, April 1998 through July 2000, and 30-year-average monthly rainfall, 1961–90, at Fernandina Beach, Florida. Thirty-year-average annual rainfall is 50.83 inches. (Data source: National Climatic Data Center, *http://cdo.ncdc.noaa.gov/plclimprod/plsql/poemain.poe*, accessed on July 12, 2001.)

Surface-Water Quality

Surface-water-quality data were collected at nine sites in April, October, and December 1999 and in March 2000 (table 1 and Appendix A). These nine sites represented many but not all NWI upland wetland classes (table 2) on Cumberland Island. Much of the variation in water-quality constituents among sampled water bodies may be attributed to (1) proximity to the ocean and the relative degree of tidal influence; (2) the amount and type of ground-water and surface-water interactions; and (3) recent and long-term rainfall patterns. Large variations in many constituents including DO, SC, Mg, K, Na, Br, Cl, and SO_4 were observed at Whitney outflow, Lake Retta outflow, and South End Pond 3 (table 4 and Appendix A). Variations in water quality at the two outflows were most likely the result of intermittent inflow or inundation by saline water from the Atlantic Ocean. Similarly, variations in water quality of South End Pond 3 were probably from temporary inundation by saline to brackish water from Cumberland Sound. Maximum concentrations for many ions were measured in water samples collected from the outflows on October 5, 2000, which was about 2 weeks after Hurricane Floyd produced storm surges and coastal flooding along the eastern U.S.—including Cumberland Island. In contrast to the low-lying, tidal- and storm-surge-affected sites, water from North Cut Pond 2A, the inland-most wetland sampled, was markedly more dilute than water from the two outflows and South End Pond 3 (table 4), and yet quite similar to rainwater.

Surface water on Cumberland Island is not used for potable water supply for humans; however, wetlands provide drinking water and habitat for animals. Although surface-water bodies sampled are not used for drinking-water supplies on the island, National Primary and Secondary Drinking-Water Regulations (U.S. Environmental Protection Agency, 2000a, b) are used in this report to provide reference levels for water-quality comparisons only.

The only measured exceedance of a National Primary Drinking-Water Regulation (U.S. Environmental Protection Agency, 2000a) in surface water was measured in one sample from Whitney outflow, which had a NO_3 concentration of 12 mg/L as nitrogen—exceeding the

Table 3. Well characteristics and summary of ground-water-level and ground-water-quality data, Cumberland Island,1966 to March 2000

[—, data not collected or information unknown; Sept., September; KBMP, Kings Bay Monitoring Project; Primary use of site: O, observation; W, withdrawal of water; Z, destroyed; Primary use of water: H, domestic; U, unused; depths to water preceded by a minus sign indicate heads above land surface; all data are available online at *http://waterdata.usgs.gov/ga*]

Location (fig.1)[1/]	Site name	Other well identifier	Latitude[2/]	Longitude[2/]	Altitude of land surface above sea level (feet)	Depth of well below land surface (feet)	Well-construction date	Primary use: Site	Primary use: Water	Water-level data: Date or period of record	Water-level data: Number of measurements	Depth to water, in feet below or above land surface: Minimum	Depth to water: Maximum	Depth to water: May 3, 1999	Depth to water: Sept. 27, 1999	Depth to water: May 8-10, 2000	Water-quality data[3/]: Other	Water-quality data: April 27-28, 1999	Water-quality data: March 6-8, 2000
Surficial aquifer (unconfined and confined water-bearing zones)																			
5	34F017	WS01 Whitney outflow NE	30°53'21"	81°24'45"	5	1	03-07-2000	Z	U	—	—	—	—	—	—	—	—	—	x
7	34F018	WS03 Whitney outflow SW	30°53'15"	81°25'02"	10	1	03-08-2000	Z	U	—	—	—	—	—	—	—	—	—	x
14	34E016	RH01 Lake Retta	30°49'54"	81°26'09"	5	1	03-07-2000	Z	U	—	—	—	—	—	—	—	—	—	x
16	34E017	RH02 Lake Retta outflow	30°49'41"	81°26'10"	10	1	03-07-2000	Z	U	—	—	—	—	—	—	—	—	—	x
A	34D006	KBMP 11	30°44'52"	81°28'00"	19.7	95	—	O	U	06-28-1990	1	13.9		—	—	—	Wilson	—	—
22	34D014	KBMP 8; Site 3	30°44'51"	81°27'59"	16.0	30	06-23-1989	O	U	06-28-1990	1	7.9		—	—	—	Wilson	—	x
B	34D015	KBMP 9; Site 3	30°44'51"	81°27'59"	16.3	72	06-23-1989	O	U	06-28-1990	1	5.5		—	—	—	Wilson	—	—
C	34D013	KBMP 7; Site 3	30°44'51"	81°27'59"	16.1	89	06-22-1989	O	U	06-28-1990	1	5.6		—	—	—	Wilson	—	—
23	34D016	KBMP 10; Site 3	30°44'51"	81°27'59"	16.1	132.4	06-25-1989	O	U	06-28-1990	1	5.6		—	—	—	Wilson	—	x
26	34D008	KBMP 2; Site 1	30°43'12"	81°28'12"	5.7	23	06-14-1989	O	U	1990-2000	[4/]15	8.6	3.5	6.1	5.5	7.1	Wilson	—	x
27	34D009	KBMP 3; Site 1	30°43'12"	81°28'12"	5.5	94	06-27-1989	O	U	06-28-1990	1	3.7		—	—	—	Wilson	—	x
D	34D007	KBMP 1; Site 1	30°43'12"	81°28'12"	6.1	146	06-14-1989	O	U	06-28-1990	1	3.7		—	—	—	Wilson	—	—
28	34D011	KBMP 5; Site 2	30°43'11"	81°27'25"	5.0	44	06-17-1989	O	U	06-28-1990	1	7.4		—	—	—	Wilson	—	x
29	34D012	KBMP 6; Site 2	30°43'11"	81°27'25"	4.9	71	06-21-1989	O	U	06-28-1990	1	6.8		—	—	—	Wilson	—	x
E	34D010	KBMP 4; Site 2	30°43'11"	81°25'25"	4.8	94	06-15-1989	O	U	06-28-1990	1	6.9		—	—	—	Wilson	—	—
Upper Floridan aquifer (confined multiple water-bearing zones)																			
F	34F012	Pomeroy, Mr.	30°58'	81°24'	10	698	1967	W	H	1968-1995	4	-26.8	-34.3	—	—	—	—	—	—
G	34F011	Platt, Mr.	30°58'	81°25'	9	702	1968	W	H	1968-1965	4	-29.3	-34.1	—	—	—	—	—	—
H	34F009	Bacon, Mr.	30°58'	81°24'	14	730	1967	W	H	1967-1995	4	-20.6	-34.4	—	—	—	—	—	—
I	34F008	Hunter, Mr.	30°57'	81°25'	12	683	1966	W	H	1967-1995	5	-26.8	-34.3	—	—	—	—	—	—
J	34F007	Richardson, Mr.	30°57'	81°24'	14	580	1967	W	H	1967-1995	5	-19.8	-30.1	—	—	—	—	—	—
K	34F006	Kingsley 2	30°57'	81°24'	10	720	1966	W	H	1967-1995	4	-31.3	-35.8	—	—	—	—	—	—
L	34F005	Kingsley 1	30°57'	81°24'	9	638	1966	W	H	1967-1995	6	-32.9	-37.9	—	—	—	—	—	—

Table 3. Well characteristics and summary of ground-water-level and ground-water-quality data, Cumberland Island,1966 to March 2000

[—, data not collected or information unknown; Sept., September; KBMP, Kings Bay Monitoring Project; Primary use of site: O, observation; W, withdrawal of water; Z, destroyed; Primary use of water: H, domestic; U, unused; depths to water preceded by a minus sign indicate heads above land surface; all data are available online at *http://waterdata.usgs.gov/ga*]

Location (fig.1)[1/]	Site name	Other well identifier	Latitude[2/]	Longitude[2/]	Altitude of land surface above sea level (feet)	Depth of well below land surface (feet)	Well-construction date	Primary use: Site	Primary use: Water	Water-level data: Date or period of record	Water-level data: Number of measurements	Depth to water, in feet below or above land surface: Minimum	Depth to water: Maximum	Depth to water: May 3, 1999	Depth to water: Sept. 27, 1999	Depth to water: May 8-10, 2000	Water-quality data[3/]: Other	Water-quality data: April 27-28, 1999	Water-quality data: March 6-8, 2000
M	34F010	Generals Mound	30°57'	81°25'	12	784	1960	W	H	1967-1995	5	-33.2	-39.5	—	—	—	—	—	—
N	34F004	Botsford, Mr.	30°56'	81°24'	9	743	1966	W	H	1966-1995	6	-33.3	-38.3	—	—	—	—	—	—
O	34F003	Keer, A.W.	30°56'	81°24'	9	720	1966	W	H	1967-1995	6	-33.7	-38.6	—	—	—	—	—	—
P	34F002	Hernley, Mr.	30°56'	81°24'	9	684	1966	W	H	1967-1995	5	-34.2	-39.0	—	—	—	—	—	—
1	34F015	Candler at water tower	30°54'	81°25'	15	—	—	W	H	1990-2000	[4/]13	-12.5	-27.6	-24.9	-22.7	-23.9	—	x	—
Q	34F016	Candler new well (1987)	30°54'	81°25'	15	—	1987	W	H	1990-2000	11	-12.9	-27.1	-17.4	-15.3	—	—	—	—
R	34F014	Squawtown Well	30°52'	81°26'	8	—	—	W	H	1984-2000	8	-21.9	-29.9	-27.2	-25.8	-23.3	—	—	—
9	34E002	Plum Orchard #2 (east well)	30°51'	81°27'	14	600	1904	W	H	1984-2000	[4/]21	-3.8	-18.1	-14.1	-12.1	-13.1	—	x	—
S	34E011	NPS Plum Orchard	30°51'	81°27'	13	—	—	W	H	1980-2000	12	-0.3	-30	—	—	-1.0	—	—	—
10	34E012	Reddick	30°50'	81°28'	12	—	—	W	H	1984-2000	24	-18.2	-24.8	-24.1	-22.6	-20.1	—	x	—
T	34E013	Yankee Paradise Trail well	30°50'	81°26'	17	—	—	W	H	1984-2000	[4/]24	-9.0	-18.1	-14.2	-13.1	-13.2	—	—	—
U	34E014	Foster	30°48'	81°27'	27	—	—	W	H	1984-2000	19	-3.0	-9.7	-5.3	-4.6	-3.1	—	—	—
19	34E003	Cumberland Island Greyfield 02	30°46'	81°28'	14	730	1931	W	H	1984-2000	[4/]21	-6.1	-15.6	-11.8	-10.2	-12.1	—	x	—
V	34E015	Missoe	30°46'	81°28'	13	—	—	W	H	1989-1998	13	-12.0	-17.3	—	—	—	—	—	—
20	34E010	Cumberland Isl 32, Rockefeller	30°46'	81°28'	10	750	—	W	H	1984-2000	[4/]22	-9.4	-16.6	-12.8	-12.1	-13.9	—	x	—
W	34E001	Cumberland Isl 01, GGS TW 3426	30°45'23"	81°28'12"	17	645	—	O	U	1984-2000	[4/]21	-0.3	-6.6	-6.4	-6.6	-1.0	St. Johns	—	—

[1/]Complete latitudes and longitudes are available online at *http://waterdata.usgs.gov/ga/nwis*.
[2/]Complete latitudes and longitudes are available online at *http://waterdata.usgs.gov/ga/nwis*.
[3/]Water-quality data: Wilson, major-ion samples collected June, July and December 1989 (Wilson, 1990); St. Johns, St. Johns River Water Management District, Florida, 11 major-ion samples collected 1994-2000 (William L. Osburn, St. Johns River Water Management District, written commun., 2000); x, samples collected by USGS as part of this study.
[4/]Water levels and chloride concentrations plotted in figure 10.

Table 4. Ranges of selected water-quality constituents at sampled water bodies, Cumberland Island, April 1999 to July 2000

[—, information unknown; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ppt, parts per thousand; NTU, nephelometric turbidity units; Na, sodium; Cl, chloride; N, nitrogen; P, phosphorus; <, less than; >, greater than; E, estimated; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, one or more observation exceeds U.S. Environmental Protection Agency secondary standards for drinking water; darker shading, exceeds U.S. Environmental Protection Agency maximum contaminant level for drinking water]

Location number (fig. 1)	Sampled water body	Number of observations or samples	Observed ranges, April 1999 to July 2000											
				Field water-quality constituents						Laboratory water-quality constituents				
			Gage height, feet	Turbidity, field, NTU	Dissolved oxygen, mg/L	pH[1], field	Specific conductance, field, µS/cm	Salinity[2], ppt	Tannin and lignin, mg/L	Sodium, dissolved, mg/L as Na	Chloride[1], dissolved, mg/L as Cl	Solids, sum of constituents[1], dissolved, mg/L	Nitrate[3], dissolved, mg/L, as N	Orthophosphorus, dissolved, mg/L, as P
			00065	61028	00300	00400	00095	—	32240	00930	00940	70301	00618	00671
2	North Cut Pond 2A	3	0.06-1.53	1.6-47	1.7-6.8	4.3-4.5	99-141	<2	4.3-5.0	7.9-13	10.2-22.4	—	<0.02-0.2	<0.020-0.013
4	Whitney Lake	4	0.74-1.2	6.3-32	2.8-6.8	5.3-5.8	179-240	<2	5.3-8.5	23-33	37.4-56	75-119	<0.02-0.04	0.065-0.111
6	Whitney outflow	4	[4]dry at gage to 1.93	6.2-50	<0.5-9.0	6.8-7.4	[4]237-39,700	<2-32	2.1-6.4	25.8-1,900	46.6-4,400	[5]132-234	<0.02-12.0	<0.02-1.30
11	Willow Pond	1	—	38	2.0	5.9	308	<2	14	42	71	153	—	—
12, 13, 15	Lake Retta complex	6	dry at gage to 0.64	1.3-130	1.0-7.5	6.4-7.3	370-1,040	<2	3.8->9.0	17.8-178	31.7-369	189-542	<0.02-2.0	0.059-0.391
17	Lake Retta outflow	4	[4]0.56-3.14	5.9-46	<0.5-9.2	6.8-7.8	[4]366-57,100	<2-46	3.0->9.0	54.4-E 1,840	83.2-3,720	[5]374-446	<0.02-1.0	0.082-1.63
25	South End Pond 3	4	0.47-1.77	4.1-320	<0.5-9.3	6.3-8.0	33,300-56,000	26-45	9.9-14	6,300-12,300	11,200-21,800	21,600-39,700	<0.02	<0.02-32.6

[1]Secondary standards for drinking water (U.S. Environmental Protection Agency, 2000b): pH, 6.5–8.5; chloride, 250 mg/L; total dissolved solids, 500 mg/L.
[2]Specific conductances were converted to salinity on a per mass basis (parts per thousand or grams dissolved solids per kilogram of seawater) using relation from McCutcheon and others (1992); temperature = 20 degrees Celsius; ocean conductivity constant = 50,000 millimhos.
[3]Maximum contaminant level (MCL) for drinking water (U.S. Environmental Protection Agency, 2000a): nitrate, 10 mg/L.
[4]Includes data from continuous monitors.
[5]Maximum total dissolved solids (TDS) concentration observed would be much higher if TDS was measured in water samples collected in October 1999.

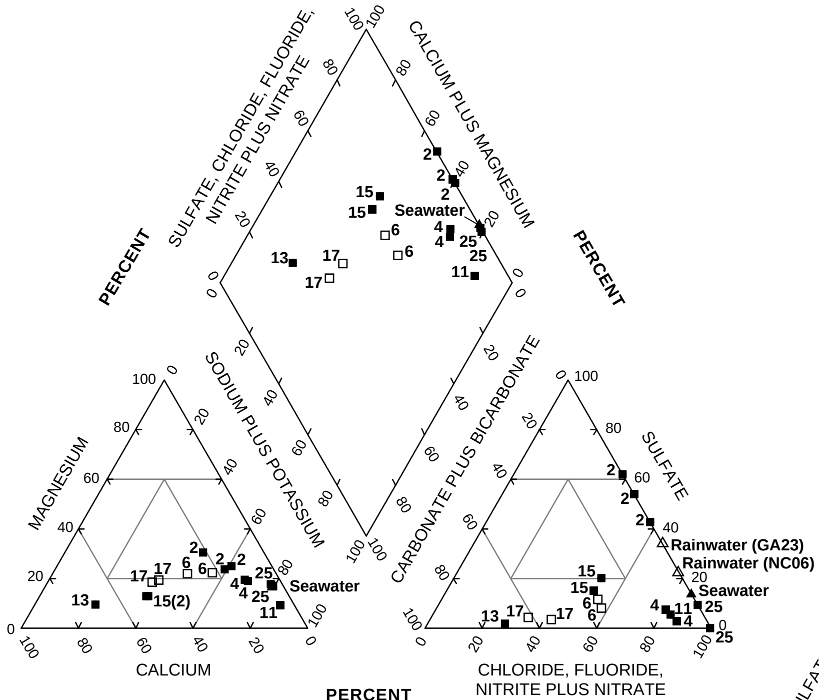
maximum contaminant level (MCL) for NO_3 of 10 mg/L. Nutrient concentrations measured in samples collected from wetlands during this study generally were low. Eighty-four percent of NO_3 concentrations and 67 percent of PO_4 concentrations measured in surface-water samples were less than or equal to 0.2 mg/L (the maximum of two laboratory minimum reporting levels (MRLs) for both constituents). Concentrations of PO_4 were high in October 1999 in samples collected from the three sites receiving seawater or brackish-water inflows because of Hurricane Floyd—South End Pond 3 (32.6 mg/L), Lake Retta outflow (1.63 mg/L), and Whitney outflow (1.30 mg/L). Horse manure or some other source of PO_4 may have washed into South End Pond 3 by the storm surge from Hurricane Floyd. Kozel (1991, p. 79, 84, and 86) noted highly eutrophic conditions in the South End Ponds from April 1988 through May 1990 based on high concentrations of PO_4 and NO_3. Kozel (1991, p. 86) stated that the summer peak in PO_4 concentrations resulted from the decrease in the volume of water in the ponds and that the late fall and winter peaks probably resulted from macrophyte and phytoplankton decomposition releasing phosphorus to the water column.

National Secondary Drinking-Water Regulations pertain primarily to aesthetic qualities of drinking water such as taste, odor, or color (U.S. Environmental Protection Agency, 2000b). In 26 surface-water samples, secondary standards for drinking water were exceeded for the following constituents: pH (10 exceedances), Cl (8), SO_4 (5), total dissolved solids (TDS) (4), Fe (2), F (1), and Mn (1) (Appendix A). According to the secondary standards, the designated lower limit for pH is 6.5; the range of pH measured in North Cut Pond 2A was 4.3 to 4.5 and in Whitney Lake was 5.3 to 5.8. Although decomposing vegetation can lower pH values in wetlands, relatively low pH values measured at North Cut Pond 2A and Whitney Lake may also be attributed to low pH rainwater. In 1999, annual rainwater pH values ranged from 4.1 to 5.4 for a site in the Okefenokee National Wildlife Refuge, Ga., about 39 miles west of Cumberland Island (National Atmospheric Deposition Program; *http://nadp.sws.uiuc.edu/nadpdata/state.asp?state=GA*, accessed on April 2001). All four surface-water samples collected from South End Pond 3 and the samples collected about 2 weeks after Hurricane Floyd from the Lake Retta outflow and Whitney outflow had concentrations of Cl, SO_4, and TDS from one to two orders of magnitude higher than secondary standards. These high concentrations are most likely the result of episodic inflows of saline or brackish water. Secondary standards were exceeded in 4 of 12 TDS measurements, in 2 of 6 Fe measurements, and in 1 of 6 Mn measurements (Appendix A). These three constituents, however, were measured in only a limited number of samples so it is not known under which hydrologic conditions secondary standards are most likely to be exceeded.

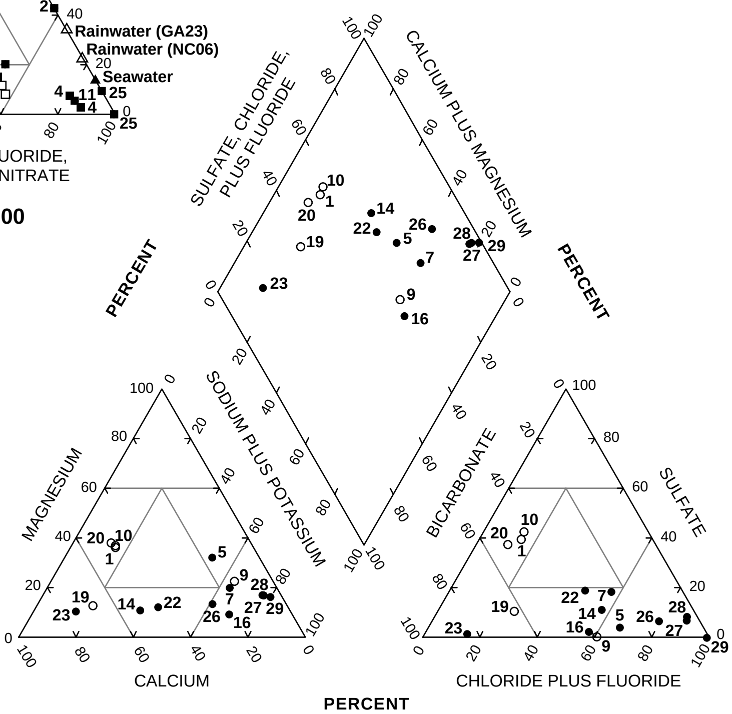
Tannin and lignin concentrations were measured in surface-water samples to estimate relative amounts of plant material breakdown products among sampled wetlands on Cumberland Island. Tannin and lignin are the refractory by-products of plant decomposition and commonly occur in a dissolved form in wetlands. In surface-water samples collected during the study, concentrations of tannin and lignin ranged from 2.1 to 14 mg/L. Samples with tannin and lignin concentrations greater than 9 mg/L needed to be diluted to quantify concentrations. The highest concentrations were consistently observed at South End Pond 3 throughout the study; however, the concentration in a single sample collected at Willow Pond was 14 mg/L. Tannin and lignin concentrations of 5 mg/L or less were most common at North Cut Pond 2A, Whitney outflow, and Lake Retta outflow (Appendix A).

The relative abundance of major ions in surface-water samples collected from Cumberland Island during this study and the relative abundance of major anions in average rainwater samples collected near the Atlantic Ocean in the southeastern U.S. (St. Simons Island, Ga., (GA23) and Beaufort, N.C., (NC06)) and in typical seawater are shown on figure 7A. Although the dominant anion in rainwater near the Atlantic Ocean is Cl, just as the dominant anion in average seawater is Cl, average dissolved-solids concentrations in rainwater are less than 10 mg/L compared to greater than 32,000 mg/L in seawater. Sodium is the dominant cation in seawater.

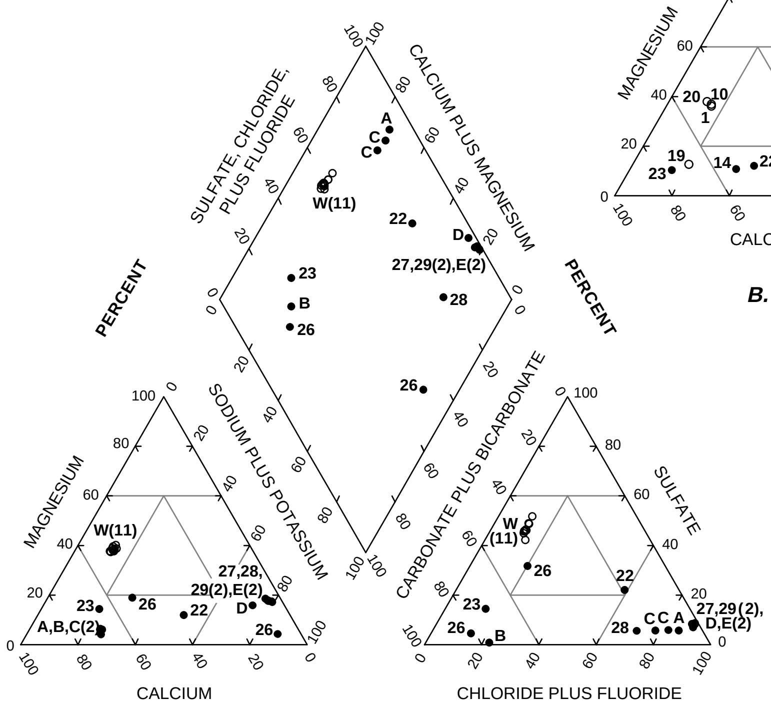
Major-ion chemistries of water in wetlands in which Na is the dominant cation and Cl is the dominant anion, such as South End Pond 3, are influenced by inundation of marine waters and input from salt aerosol and rainwater (fig. 7A). South End Pond 3 is intermittently inundated by saline or brackish water from Cumberland Sound and much of this seawater evaporates between major storms. During the study period, the major-ion composition of water from South End Pond 3 was similar to seawater and the TDS ranged from more diluted to more concentrated than average seawater. Although partly protected by high altitude rear dunes (fig. 3); and therefore, much less subject to inundation by seawater than South End Ponds, the major ion chemistries of water samples from Whitney Lake and Willow Pond were also dominated by Na–Cl. These two water bodies are close enough to the Atlantic Ocean that salt aerosols may influence major-ion chemistries of water



A. **Surface water, April 1999 through March 2000**



B. **Ground water, April 1999 and March 2000**



C. **Ground water, 1989 and 1994–2000**

Figure 7. Trilinear diagrams showing the relative abundance of major ions for *(A)* surface water, April 1999 through March 2000; *(B)* ground water, April 1999 and March 2000; and *(C)* ground water, 1989 and 1994–2000. (Numbers in parentheses are number of samples.)

EXPLANATION AND ADDITIONAL INFORMATION FOR FIGURE 7

A. SURFACE WATER

Location number (Fig. 1)	Surface-water site name	Dissolved solids, in mg/L, 1999, Apr	1999, Oct	1999, Dec	2000, Mar
■ Palustrine wetlands					
2	North Cut Pond 2A	42	54	68	Dry
4	Whitney Lake	75	—	—	119
11	Willow Pond	—	—	—	153
13	Lake Retta complex 420 feet south of foot bridge	189	—	—	—
15	Lake Retta	280	—	—	542
25	South End Pond 3	39,700	—	—	21,600
□ Estuarine wetlands					
6	Whitney outflow	132	—	—	234
17	Lake Retta outflow	374	—	—	446
▲ Average seawater (Stumm and Morgan, 1996, p. 899)					
—	Average seawater	32,800			
△ Average rainwater[1] (data from *http://nadp.sws.uiuc.edu/nadpdata*, accessed on November 2, 2000)					
—	GA23, St. Simons Island, Ga., 1985–88 (elevation 7 feet, 31°13'31" 81°23'32")	3.4			
—	NC06, Beaufort, N.C., Jan. 1999–April 2000 (elevation 7 feet, 34°53'04" 76°37'17")	5.0			

[1]Only anion composition plotted for average rainwater. Hydrogen ion and ammonium comprise 25–36 percent of major cation composition for two rainwater sites

B. AND *C.* GROUND WATER

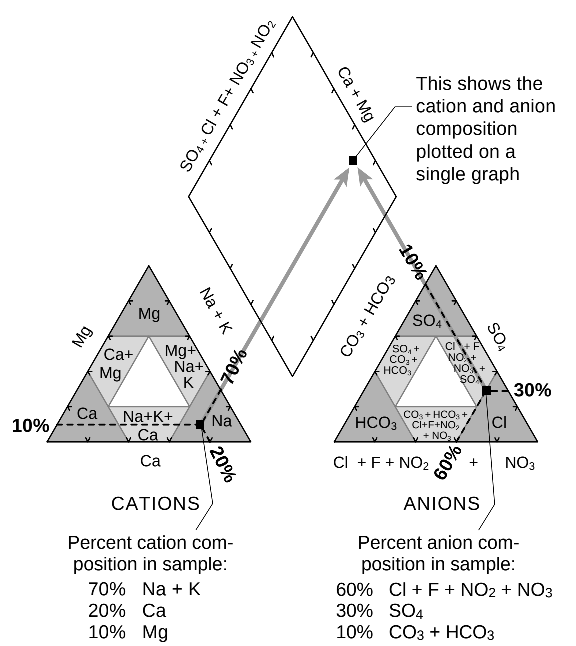
Location number or letter (Fig. 1)	Ground-water site name	Dissolved solids, in mg/L, [2]1989, or [3]1994–2000	Apr 1999	Mar 2000
● Surficial aquifer (unconfined and confined water-bearing zones)				
5	WS01 Whitney Outflow NE	—	—	160
7	WS03 Whitney Outflow SW	—	—	194
14	RH01 Lake Retta	—	—	508
16	RH02 Lake Retta Outflow	—	—	938
A	KBMP 11	[2]2,010	—	—
22	KBMP 8; Site 3	[2]398	—	418
B	KBMP 9; Site 3	[2]346	—	—
C	KBMP 7; Site 3	[2]1,290–1,590	—	—
23	KBMP 10; Site 3	[2]345	—	252
26	KBMP 2; Site 1	[2]440–563	—	1,660
27	KBMP 3; Site 1	[2]24,000	—	14,500
D	KBMP 1; Site 1	[2]1,200	—	—
28	KBMP 5; Site 2	[2]1,390	—	12,900
29	KBMP 6; Site 2	[2]31,500–31,100	—	30,900
E	KBMP 4; Site 2	[2]24,200–24,900	—	—
○ Upper Floridan aquifer (confined multiple water-bearing zones)				
1	Candler at water tower	—	422	—
9	Plum Orchard #2 (eastwell)	—	82	—
10	Reddick	—	423	—
19	CumberlandIsl Greyfield 02	—	216	—
20	CumberlandIsl 32, Rockefeller	—	467	—
W	CumberlandIsl 01, GGS TW 3424	[3]E 484–538	—	—

[2]Wilson, 1990

[3]William L. Osburn, St Johns River Water Management District, Florida, written commun., 2001

[mg/L, milligrams per liter; —, data not collected or information not known; E, estimated; (light shading), less than 100; (dark shading), greater than 10,000]

HOW TO READ A TRILINEAR DIAGRAM



HYDROCHEMICAL FACIES

- (dark shading) Dominant cation or anion
- (light shading) Dominant cations or anions
- (no shading) Mixed—no dominant cations and (or) anions

CHEMICAL ABBREVIATIONS

BICARBONATE	HCO_3
CALCIUM	Ca
CARBONATE	CO_3
CHLORIDE	Cl
FLUORIDE	F
SODIUM	Na
SULFATE	SO_4
MAGNESIUM	Mg
NITRATE	NO_3
NITRITE	NO_2
POTASSIUM	K

Trilinear diagrams (similar to Piper, 1944) are useful in determining which samples have similar major-ion compositions (Hem, 1985, p. 178). Trilinear diagrams have relative percentages of major cations plotted on the lower-left triangle, relative percentages of major anions plotted on the lower-right triangle, and those percentages are projected onto the diamond above. A straight line between two points in any sector of a trilinear diagram indicates the ionic proportions of all possible simple mixtures of waters represented by the two end points of the line. In this report, a cation or anion is considered dominant when its relative proportion to the sum of cations or anions is greater than or equal to 60 percent. If the proportion of the sum of any two cations or two anions is equal to or greater than 80 percent, they are considered dominant. When water is designated as having "no dominant anion or cation", nearly equal proportions of major ions are present and it has a "mixed" hydrochemical facies (Katz, 1992). The relative concentrations of ions are not graphically displayed in figure 7, but concentrations of total dissolved solids are listed in the explanation.

in Whitney Lake and Willow Pond; however, TDS concentrations are less than 160 mg/L. The rear dunes may dam much of the rainwater that falls on and near Whitney Lake and Willow Pond, thus increasing the influence of rainwater on the major-ion chemistries of these water bodies.

The major-ion chemistry of water samples from North Cut Pond 2A is mixed with Mg–Na as the dominant cations and Cl–SO_4 as the dominant anions. Major-ion chemistry and very low TDS (less than 70 mg/L) concentrations of water from North Cut Pond 2A indicate that rainwater is probably the dominant source of water to the wetlands surrounding North Cut Ponds.

In contrast to Na–Cl dominated waters, water samples that plot near the lower left triangles within the cation and anion triangles in figure 7 have major-ion chemistries where Ca is the dominant cation and HCO_3 is the dominant anion. The Upper Floridan aquifer is composed of a vertically continuous sequence of carbonate rocks, and waters in contact with the aquifer materials for sufficient time periods are most commonly described by the Ca–HCO_3 and Ca–Mg–HCO_3 hydrochemical facies (Katz, 1992, p. 34-35). The major-ion chemistries of water in wetlands dominated by Ca–HCO_3 probably indicate that ground-water inflow has more influence on major-ion composition in these wetlands than rainfall or marine waters. The major-ion chemistries of Lake Retta and the two outflows are typically mixed—predominated by Na–Ca–HCO_3–Cl. The major-ion chemistry of the sample collected at the Lake Retta complex was dominated by Ca–HCO_3. Although the Lake Retta complex wetlands are closer to the Atlantic Ocean than is Willow Pond, the major-ion chemistry of the sample collected in April 1999 from the Lake Retta complex appears to be more influenced by ground water whereas the sample collected in March 2000 from Willow Pond appears to be more influenced by salt aerosols or rainwater. However, Hillestad and others (1975, p. 51 and 56) stated that Lake Retta periodically is inundated by the Atlantic Ocean. Because only one sample from Willow Pond and Lake Retta complex and only two samples from Lake Retta were analyzed for major ions, there are not enough data collected over a variety of hydrologic conditions to speculate what factors might control apparent differences in major-ion compositions of water from wetlands in this part of Cumberland Island.

Trace-element concentrations in surface-water samples generally were low. Sixty-four percent of all trace-element analyses were less than the minimum laboratory reporting limits that ranged from 0.1 to 10 μg/L, depending upon the constituent and the analysis (Appendix A). Exceptions include Fe concentrations in samples collected from Whitney Lake and Willow Pond that exceeded the secondary standard for drinking water of 300 μg/L of Fe (U.S. Environmental Protection Agency, 2000b). One sample collected after Hurricane Floyd from South End Pond 3 had Zn concentrations just less than the Criterion Continuous Concentration (CCC) for Zn—a criterion for the protection of aquatic life (U.S. Environmental Protection Agency, 1999).

From April 26-30, 1999, Atlantic Ocean water was collected each day from five Cumberland Island beach locations and analyzed for enterococci (Appendix B). At each site, dip samples were collected where the ocean was about 1.5 and 3 ft deep. The U.S. Environmental Protection Agency (USEPA) recommended standard for enterococci in marine recreational waters is a geometric mean of 35 col/100 mL (based on at least four samples collected from a given site over a 30-day period at an interval not less than 24 hours) or a single-sample maximum of 104 col/100 mL (U.S. Environmental Protection Agency, 1986). The USEPA geometric mean standard for enterococci is based on a predicted 19 gastrointestinal illnesses per 1,000 swimmers at marine beaches during steady-state dry-weather conditions (U.S. Environmental Protection Agency, 1986, p. 9 and Table 4). As of 2001, the State of Georgia had not adopted the enterococci standards for marine recreational waters. The geometric-mean concentrations of enterococci for the five sites sampled were less than the USEPA recommended geometric-mean criteria of 35 col/100 mL, and all enterococci concentrations measured were less than the USEPA recommended single-sample maximum of 104 col/100 mL for marine water bathing beaches (U.S. Environmental Protection Agency, 1986; Figure 8; Appendix B). Enterococci concentrations in samples collected where water depths were about 1.5 ft ranged from less than 1 to 29 col/100 mL; whereas, enterococci concentrations collected where water depths were about 3 ft ranged from less than 1 to 57 col/100 mL. The highest enterococci concentration measured as part of this study, 57 col/100 mL, was from a sample collected where water depths were about 3 ft at Sea Camp Beach on April 29, 1999. Geometric-mean concentrations of enterococci in samples collected where water depths were about 3 ft gradually decreased from 12 col/100 mL at North Cut Road Beach on the north end of the island to 4 col/100 mL at Dungeness Beach on the south end of the island. At all five beach sites sampled, geometric means were 5 col/100 mL for samples collected where water depths were about 1.5 ft. Although no exceedances of geometric mean microbial standards were observed, potential local sources of enterococci to the near-shore Atlantic Ocean include nonpoint sources such as wildlife and feral animals on Cumberland Island and point and nonpoint sources from areas north of Cumberland Island.

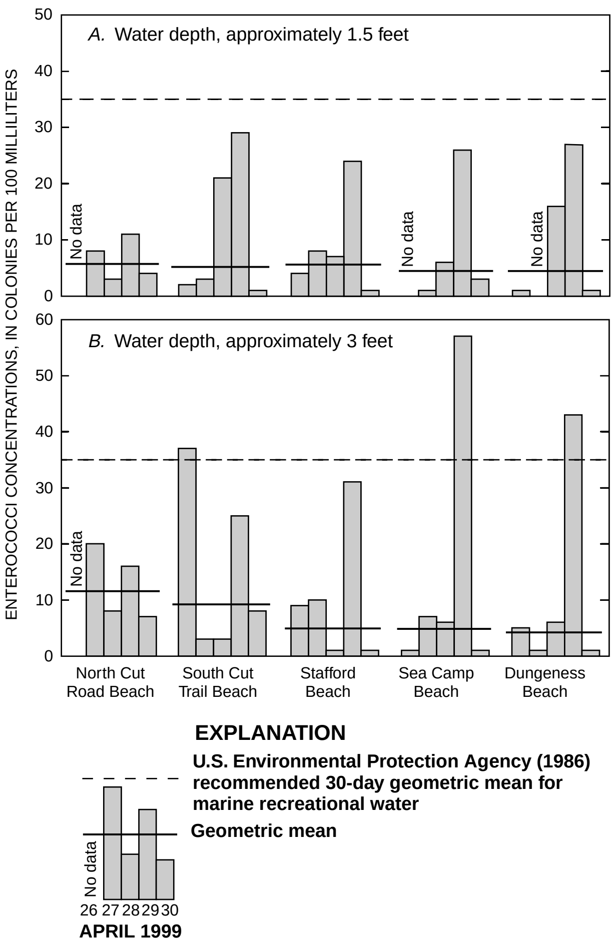


Figure 8. Enterococci concentrations of the near-shore Atlantic Ocean at five Cumberland Island beaches, Georgia, April 26–30, 1999.

Aquatic Communities

Collectively, 54 aquatic invertebrate taxa were identified in samples collected from the six water bodies during April and December 1999 sampling (table 5). Aquatic insects, which were represented by 42 insecta taxa, dominated invertebrate communities in freshwater wetland habitats on Cumberland Island; however, 5 gastropod taxa, 5 malacostraca taxa, 1 Hirudinea, and 1 Arachnida also were collected. Samples collected from wetlands during April yielded 43 taxa of invertebrates and samples collected during December yielded 35 taxa. During the April sampling, invertebrate taxa richness ranged from 18 taxa at Whitney Lake to 3 taxa at South End Pond 3; whereas, during December, taxa richness ranged from 14 taxa at North Cut Pond 2A to only 2 species in South End Pond 3. Except for the invertebrate community in North Cut Pond 2A, invertebrate communities were more diverse during April than in December.

The majority of aquatic insects collected at Cumberland Island were of the orders Hemiptera and Coleoptera. Water boatmen (Corixidae) were the most abundant Hemipteran family and were represented by four taxa. Most Hemipteran are classified behaviorally as predaceous, lentic swimmers (Merritt and Cummins, 1984). Water boatmen were widely distributed among all sampled wetland areas and were collected from each wetland habitat sampled during April or December. Water scavenger beetles (Hydrophilidae) and predaceous diving beetles (Dytiscidae) were the most abundant Coleopteran families in sampled wetlands on Cumberland Island and were represented by five and six taxa, respectively. Water scavenger beetles are classified behaviorally as swimmers and divers and are trophic generalists, exhibiting a wide range of feeding strategies such as consuming detritus and piercing and sucking fluids out of living plant tissues (Merritt and Cummins, 1984). Taxa from Hemipteran and Coleopteran orders have the ability to utilize oxygen from the surface of the water bodies and can fly as adults (Merritt and Cummins, 1984), which makes them well adapted for life in low-oxygen wetland habitats with short or unpredictable hydroperiods.

Adult dragonflies and damselflies (Order: odonata) were commonly observed in flight, and immature odonates were represented by 4 families and 12 taxa in wetlands on Cumberland Island. Members of the families Libellulidae, Aeshnidae, and Coenagrionidae were collected mainly from Whitney Lake, the beach outflows, and North Cut Pond 2A. These taxa are able to utilize the vascular hydrophytes present at each of these sites as habitat and have special modifications for vertical movement on stems and leaves. These species of dragonflies and damselflies also have a considerable tolerance for low-oxygen levels and are well adapted for life in lentic waters (Merritt and Cummins, 1984). Dragonflies and damselflies were most commonly found in association with dense aquatic vegetation and floating macrophytes. Two taxa of mayflies (Ephemeroptera), *Callibaetis* sp. and *Caenis* sp., were collected only from Whitney Lake and the beach outflows, and appear to be specifically associated with areas of dense emergent aquatic vegetation.

Table 5. Composition of aquatic-invertebrate communities in sampled water bodies, Cumberland Island, April and December 1999

[—, invertebrate not collected; X, invertebrate collected; Dec, December]

Taxon (common name[1/]) Order: suborder / Family / *Genus species*	North Cut Pond 2A (2) April	North Cut Pond 2A (2) Dec	Whitney Lake (4) April	Whitney Lake (4) Dec	Whitney outflow (6) April	Whitney outflow (6) Dec	Lake Retta (15) April	Lake Retta (15) Dec	Lake Retta outflow (17) April	Lake Retta outflow (17) Dec	South End Pond 3 (25) April	South End Pond 3 (25) Dec	All six water bodies April	All six water bodies Dec
Hirudinea (leeches)														
RHYNCHOBDELLIDA														
Erpobdella punctata (Leidy)	—	—	X	—	—	X	X	—	—	—	—	—	X	X
Gastropoda (snails)														
LYMNOPHILA														
Lymnaeidea (mimic pond snails)														
Pseudosuccinea columella (Say)	—	—	X	—	—	—	—	—	—	—	—	—	X	—
Physidae														
Physella sp.	—	—	X	X	—	—	X	X	—	—	—	—	X	X
Planorbidae														
Planorbella sp.	—	—	—	—	—	—	X	X	X	—	—	—	X	X
UNKNOWN														
Unknown														
unidentified sp. 1	—	X	—	—	—	—	—	—	—	—	—	—	—	X
unidentified sp. 2	—	—	—	—	—	—	—	—	—	—	X	—	X	—
Arachinida														
ARANEAE (spiders)														
Tetragnatidae														
Tetragnatha sp.	—	—	—	—	—	X	—	—	—	—	—	—	—	X
Malacostraca														
AMPHIPODA (scuds)														
Gammaridae														
unidentified sp.	X	X	—	X	—	—	—	X	—	—	—	—	X	X
ISOPODA (sow bugs)														
Asellidae														
Asellus sp.	—	—	—	—	—	—	—	—	—	—	—	X	—	X
DECAPODA														
Astacidae (crayfishes)														
Procambarus sp.	X	X	—	—	—	—	X	X	—	—	—	—	X	X
Atyidae (shrimps)														
Penaeus sp.	—	—	—	—	X	X	—	—	X	X	—	—	X	X
Portunidae (crabs)														
Callinectes sp.	—	—	—	—	X	X	—	—	—	X	—	—	X	X

Table 5. Composition of aquatic-invertebrate communities in sampled water bodies, Cumberland Island, April and December 1999
[—, invertebrate not collected; X, invertebrate collected; Dec, December]

Taxon (common name[1/])	Sampled water body (location numbers in figure 1)												All six water bodies	
Order: suborder **Family** *Genus species*	North Cut Pond 2A (2)		Whitney Lake (4)		Whitney outflow (6)		Lake Retta (15)		Lake Retta outflow (17)		South End Pond 3 (25)			
	April	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April	Dec
Insecta														
COLEOPTERA														
Dytiscidae (predaceous diving beetles)														
Agabus sp.	—	X	—	—	—	—	X	—	—	—	—	—	X	X
Cybister sp.	—	—	X	X	—	—	—	—	—	—	—	—	X	X
Hydaticus bimarginatus (Say)	—	—	—	—	—	—	—	X	—	—	—	—	—	X
Hydaticus sp.	X	X	X	—	—	—	—	X	—	—	—	—	X	X
Hydroporini sp.	X	X	—	—	—	—	—	—	—	—	—	—	X	X
Laccophilus sp.	X	X	—	—	—	—	—	—	—	—	—	—	X	X
Gyrinidae (whirligig beetles)														
Dineutus emarginatus (Say)	—	—	—	—	—	—	X	—	X	—	—	—	X	—
Haliplidae (crawling water beetles)														
Peltodytes lengi Roberts	—	—	—	X	X	X	—	X	X	X	—	—	X	X
Hydrophilidae (water scavenger beetles)														
Berosus sp.	X	—	—	—	—	—	—	—	X	—	—	—	X	—
Hydrochara sp.	—	—	—	—	—	—	X	—	—	—	—	—	X	—
Tropisternus lateralis (Fabricius)	—	—	—	—	—	—	X	—	—	—	—	—	X	—
Tropisternus sp.	X	—	X	—	—	—	X	—	—	X	X	—	X	X
unidentified sp.	—	—	—	—	X	—	—	—	—	—	—	—	X	—
Noteridae (burrowing water beetles)														
Hydrocanthus sp.	X	—	X	—	—	—	—	—	—	—	—	—	X	—
DIPTERA														
Chironomidae (midges)														
unidentified sp.	—	—	—	X	X	X	—	—	—	X	—	—	X	X
EPHEMEROPTERA														
Baetidae (mayflies)														
Callibaetis sp.	—	—	—	—	X	—	—	—	X	X	—	—	X	X
Caenidae (mayflies)														
Caenis sp.	—	—	—	X	—	—	—	—	—	—	—	—	—	X
HEMIPTERA														
Belostomatidae (giant water bugs)														
Belostoma sp.	—	—	—	—	—	—	—	—	X	—	—	—	X	—
Corixidae (water boatmen)														
Hesperocorixa sp.	—	X	—	—	—	—	—	—	—	—	—	—	—	X
Trichocorixa sp.	X	—	—	—	X	—	—	—	—	X	X	—	X	X
unidentified sp.	—	—	—	—	X	—	—	—	—	—	—	—	X	—
Naucoridae (creeping water bugs)														
Pelocoris sp.	X	—	X	X	X	—	—	—	—	—	—	—	X	X
Nepidae (water scorpions)														
Ranatra australis Hungerford	—	—	X	—	X	—	—	—	X	—	—	—	X	—
Ranatra sp.	—	—	—	—	X	—	—	—	—	—	—	—	X	—

Table 5. Composition of aquatic-invertebrate communities in sampled water bodies, Cumberland Island, April and December 1999
[—, invertebrate not collected; X, invertebrate collected; Dec, December]

Taxon (common name[1/])	Sampled water body (location numbers in figure 1)												All six water bodies	
Order: suborder **Family** *Genus species*	North Cut Pond 2A (2)		Whitney Lake (4)		Whitney outflow (6)		Lake Retta (15)		Lake Retta outflow (17)		South End Pond 3 (25)			
	April	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April	Dec
Insecta—Continued														
HEMIPTERA—Continued														
Notonectidae (backswimmers)														
Buenoa sp.	—	X	—	—	—	—	—	—	—	—	—	—	—	X
Notonecta sp.	—	X	—	—	—	—	X	X	—	—	—	X	X	X
Veliidae (little water striders)														
Limnoporous canaliculatus (Say)	X	—	—	—	—	—	—	—	—	—	—	—	X	—
Platyvelia brachialis (Stal)	—	—	X	—	—	—	—	—	—	—	—	—	X	—
LEPEDOPTERA (butterflies)														
Pyralidae														
unidentified sp.	—	—	—	—	—	—	—	—	—	X	—	—	—	X
ODONATA: ANISOPTERA														
Aeshnidae (darners)														
Anax junius (Drury)	—	X	—	X	—	—	—	X	X	—	—	—	X	X
Libellulidae (skimmers)														
Erythemis sp.	—	—	X	X	X	—	—	—	—	—	—	—	X	X
Libellula sp.	—	X	—	—	—	—	—	—	—	—	—	—	—	X
Miathyria marcella (Selys)	—	—	X	X	—	—	—	—	—	—	—	—	X	X
Pachydiplex longipennis (Burmiester)	—	X	X	—	—	—	—	—	—	—	—	—	X	X
unidentified sp.	—	—	X	—	—	—	—	—	—	—	—	—	X	—
ODONATA: ZYGOPTERA														
Coenagrionidae (pond damselflies)														
Enallagma sp.	—	—	X	—	—	—	—	—	—	—	—	—	X	—
Ischnura sp.	—	—	—	X	X	—	—	—	X	—	—	—	X	X
Telebasis byersi Westfall	—	—	X	—	—	—	—	—	—	—	—	—	X	—
unidentified sp.	—	—	—	—	—	—	—	—	—	X	—	—	—	X
Lestidae (spread winged damselflies)														
Lestes sp.	—	X	—	—	—	—	—	—	—	—	—	—	—	X
Lestes vigilax (Hagen)	—	—	X	—	—	—	—	—	—	—	—	—	X	—
ORTHOPTERA (grasshoppers)														
Acrididae														
Stenacris sp.	—	—	X	—	—	—	—	—	—	—	—	—	X	—
Number of insect taxa, by sampling date	9	11	15	9	11	2	6	5	8	7	2	1	34	25
Number of invertebrate taxa, by sampling date	11	14	18	11	13	6	10	9	10	9	3	2	43	35
Number of insect taxa, by water body	17		20		11		10		13		3		42	
Number of invertebrate taxa, by water body	20		24		15		15		16		5		54	

[1/]Common names from Brigham and others (1982).

Other non-insect aquatic invertebrates such as freshwater crayfish (*Procambarus* sp.), scuds (Gammaridae), and aquatic sow bugs (*Asellus* sp.) were restricted to freshwater interdunal scrub-shrub wetlands areas and semi-permanent and seasonal water bodies. Marine invertebrates, including shrimp (*Penaeus* sp.) and crabs (*Callinectes* sp.), were restricted to brackish water in beach outflows that had intermittent surface connections and exchanges of water with the Atlantic Ocean.

Nine species of fishes were collected on Cumberland Island during April and December 1999 sampling (table 6). Mosquitofish (*Gambusia affinis*) were the most commonly collected species of fish on Cumberland Island and were found in all water bodies sampled during April and in four of six water bodies sampled during December (table 6). Mosquitofish are highly tolerant of extreme water-quality conditions such as high temperatures and low DO concentrations (Jenkins and Burkhead, 1994) making them especially well suited for life in the barrier island wetlands investigated in this study. Sailfin mollys (*Poecilia latipinna*) were also commonly collected on Cumberland Island; however, these species were only collected from water bodies near the ocean or sound. Both mosquitofish and sailfin mollys can tolerate saline conditions and bear their young live, allowing them to quickly populate water bodies with short hydroperiods.

Striped mullet (*Mugil cephalis*) and sheepshead minnow (*Cyprinodon variedates*) were collected from three of six water bodies sampled on Cumberland Island—all of which had direct, but temporary connections to the Atlantic Ocean or Cumberland Sound. Tarpon snook (*Centropomus pectinatus*), mottled mojarras (*Eucinostomus lefroyi*), and striped killifish (*Fundalus majalis*) were only collected from beach outflows that were inundated with seawater on an intermittent basis during this study. Warmouth (*Lepomis gulosis*) and bluegill (*Lepomis macrochirus*) are freshwater fish species and were only collected from Whitney Lake, the only wetland area sampled with deep (greater than 3 ft), open-water habitat.

Table 6. Composition of fish communities in sampled water bodies, Cumberland Island, April and December 1999

[—, fish not collected; X, fish collected; Dec, December]

Scientific name	Common name	Sampled water body (location numbers from figure 1)												All six water bodies	
		North Cut Pond 2A (2)		Whitney Lake (4)		Whitney outflow (6)		Lake Retta (15)		Lake Retta outflow (17)		South End Pond 3 (25)			
Family *Genus species*		April	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April	Dec
Cyprinodontidae	**Killifishes**														
Cyprinodon variegates	Sheepshead minnow	—	—	—	—	X	X	—	—	X	X	X	X	X	X
Fundulus majalis	Striped killifish	—	—	—	—	—	—	—	—	—	X	—	—	—	X
Poeciliidae	**Livebearers**														
Gambusia affinis	Mosquitofish	X	X	X	X	X	X	X	—	X	X	X	—	X	X
Poecilia latipinna	Sailfin molly	—	—	—	—	X	—	X	—	X	—	—	X	X	X
Centropomidae	**Snooks**														
Centropomus pectinatus	Tarpon snook	—	—	—	—	—	X	—	—	—	—	—	—	—	X
Gerreidae	**Mojarras**														
Eucinostomus lefroyi	Mottled mojarra	—	—	—	—	X	X	—	—	X	X	—	—	X	X
Centrarchidae	**Sunfishes and Basses**														
Lepomis gulosus	Warmouth	—	—	X	—	—	—	—	—	—	—	—	—	X	—
Lepomis macrochirus	Bluegill	—	—	X	X	—	—	—	—	—	—	—	—	X	X
Mugilidae	**Mullets**														
Mugil cephalus	Striped mullet	—	—	—	—	X	—	—	—	X	—	—	X	X	X
Number of fish species, by sampling date		1	1	3	2	5	4	2	0	5	4	2	3	7	8
Number of fish species, by water body		1		3		6		2		6		4		9	

Descriptions of Water Bodies

Characteristics of six wetland areas sampled as part of this study are described below. Descriptions include information from NWI, previous investigations, field observations and measurements, and laboratory results.

North Cut Ponds

The North Cut Ponds are depressional features in an upland setting about 25 ft above sea level and are not associated with foredunes or rear dunes (fig. 3). These wetland areas are classified as palustrine emergent and represent about 4 percent of the wetland types on Cumberland Island. Because topographic relief is low, there is minimum potential for ground-water inflow from upland areas; in contrast to wetlands associated with dune and swale topography. This results in only minor contributions of ground water to the water in North Cut Ponds.

North Cut Pond 2A is about 2 miles inland from the ocean and contained the lowest major-ion concentrations and SC of the sampled surface-water bodies (Appendix A). NO_3 and PO_4 concentrations in North Cut Pond 2A were low in all three samples. Major-ion composition of North Cut Pond 2A is Na–Mg–Cl–SO_4. Water-quality samples from North Cut Pond 2A were the only surface-water samples with a higher percentage of SO_4 than rainwater. SC values less than 150 µS/cm, pH values less than 4.5 (which were the lowest measured values in surface-water samples), and major-ion composition suggest that rainfall may be the major source of water and evaporation may be the major loss of water from the wetlands surrounding North Cut Pond. The small wetlands that comprise the North Cut Ponds area are more influenced by precipitation, more isolated from other water bodies, and have shorter hydroperiods than dune-associated wetlands.

The aquatic-invertebrate community of North Cut Pond 2A was composed of 20 taxa and was among the most taxonomically rich of those wetlands sampled during this study (table 5). The aquatic-invertebrate community in North Cut Pond 2A was dominated by Coleoptera and Hemiptera, although Odonates were common in the December 1999 sample. Unlike other wetlands sampled during this study, invertebrate richness in North Cut Pond 2A was higher during December than in April. Fish communities of North Cut Pond 2A were the least diverse of all sampled water bodies on Cumberland Island and consisted of only mosquitofish, which were collected in April and December 1999 (table 6).

Whitney Lake

Whitney Lake is the largest and most permanent freshwater body on Cumberland Island, and is classified by the NWI as palustrine emergent and palustrine with an unconsolidated bottom. The location of Whitney Lake at the northern end of the Sweetwater Lake Complex (fig. 1) and just west of a large system of dunes (fig. 3) suggests similar hydrogeomorphology to the Sweetwater Lake Complex. Due to its large size and large amount of open water, however, Whitney Lake is distinctly different from other wetlands and is a unique lentic feature on Cumberland Island. Whitney Lake has about 10 acres of open-water habitat, and the maximum depth approaches 5 ft in some areas near its eastern edge (Lambert, 1992). A dense growth of emergent and floating aquatic vegetation surrounds the open-water portion of this lake. Comparison of photos taken in 1991 (Lambert, 1992) to those taken for the present study suggests that the area of floating vegetation on the western side of the lake has grown considerably in recent years. Although Whitney Lake is within 2,000 ft of the ocean, foredunes about 15 ft in height and rear dunes about 30 ft in height partially shield the lake from ocean breezes containing salt aerosols (fig. 3).

In general, the water quality of Whitney Lake and North Cut Pond 2A was the most consistent of the wetlands sampled during this study (Appendix A, fig. 7A). Although the hydrochemical facies of Whitney Lake samples was Na–Cl (fig. 7A), relatively low TDS (75 to 119 mg/L), Na (23 to 33 mg/L), and Cl (37 to 56 mg/L) concentrations, and SC (179 to 240 µS/cm) indicate that seawater and salt aerosols from the ocean have little effect on water quality of the lake. Whitney Lake may be well flushed by ground-water throughflow from uplands toward and into the beach outflows. The hydrochemical facies of shallow ground water near Whitney outflow (fig. 7B) was more similar to Whitney Lake water than to water collected from the Whitney outflow. This hydrochemical similarity suggests the presence of shallow freshwater near the foredune area adjacent to the beaches on the north end of Cumberland Island, and indicates upgradient source areas for recharge of freshwater that discharges into the beach outflows. The lowest concentrations of SO_4 (1.7 to 7.8 mg/L), acid neutralizing capacity (ANC) (12 mg/L), and alkalinity 6.7 mg/L) were measured in Whitney Lake samples. PO_4 concentrations measured in Whitney Lake (0.065 to 0.11 mg/L) are within the range expected to result in algal blooms and to support eutrophication if phosphorus existed as the limiting factor in the lake (Dunne and Leopold, 1978). Trace-element concentrations were low in Whitney

Lake with the exception of Fe and Mn (Appendix A). In the March 2000 Whitney Lake sample, the Fe concentration of 760 μg/L was the highest trace-element concentration measured in wetlands sampled on Cumberland Island and exceeded the secondary standard of 300 μg/L (U.S. Environmental Protection Agency, 2000b). The Mn concentration in this sample was 44 μg/L, which is slightly less than the secondary standard of 50 μg/L (U.S. Environmental Protection Agency, 2000b). The source of moderately high concentrations of Fe and Mn in Whitney Lake may be ground water. Shallow ground-water samples collected near the Whitney outflow also had Fe concentrations (720 to 2,100 μg/L) exceeding the secondary standard for Fe and Mn concentrations (27 to 41 μg/L) similar to the 44 μg/L of Mn measured in Whitney Lake (Appendix A, C). Topographic setting of Whitney Lake and surrounding dunes, hydrochemical facies, and low but relatively consistent pH (5.3 to 5.8) and SC (179 to 240 μS/cm) indicate that in addition to seepage from ground water, rainwater also is a major source of water for Whitney Lake.

With 24 taxa of aquatic invertebrates identified from samples collected in April and December 1999, the aquatic invertebrate community at Whitney Lake was the richest taxonomically of all wetlands sampled during this study. Invertebrate communities of Whitney Lake were richer during April when 18 taxa were collected compared to December when only 11 taxa were collected. Six taxa that were collected only from Whitney Lake include a mayfly (*Caenis* sp.), a little water strider (*Platyvelia brachialis*), an unidentified skimmer (Libellulidae), two taxa of pond damsel fly (*Enallagma* sp. and *Telebasis byersi*), a spread winged damsel fly (*Lestes vigilax*), and a semi-aquatic grass hopper (*Stenacris* sp.). Most aquatic invertebrates collected from Whitney Lake were associated with floating and emergent aquatic vegetation.

Only three species of fishes were collected at Whitney Lake; however, adequate sampling of the open-water areas of Whitney Lake would have required techniques and equipment that were beyond the scope of this study and that would be difficult to implement within a wilderness area. Mosquitofish, bluegill, and warmouth were collected in the shallow, near-shore waters of Whitney Lake. In addition to the three species of fishes collected, largemouth bass (*Micropterous salmoides*), striped mullets, and yellow bullheads (*Amerius natalis*) were collected from Whitney Lake in September 1973; these species probably were introduced to the lake for sport fishing (Hillestad and others, 1975).

Willow Pond

Willow Pond is a palustrine wetland system with an unconsolidated bottom, and the pond represents less than 1 percent of freshwater wetlands on Cumberland Island. The number and extent of open-water bodies that comprise Willow Pond varies greatly depending on antecedent rainfall conditions. When the Willow Pond sample was collected from the northernmost pond, the rainfall deficit was more than 26 inches for the 24 months before March 2000 (fig. 6); therefore, concentrations of chemical constituents may be higher in this sample than under more normal or wetter than normal hydrologic conditions. Water quality at the northernmost Willow Pond was most similar to water quality measured in the four Whitney Lake samples (table 4, fig. 7A, Appendix A). The relative percent of Na and Cl in the Willow Pond sample placed its major-ion chemistry within the Na–Cl hydrochemical facies (fig. 7A). The tannin and lignin concentration in Willow Pond was 14 mg/L, which was one of the highest concentrations measured during the study. The dissolved Fe concentration of 310 μg/L was the second highest measured in wetlands on the island and exceeded the secondary standard of 300 μg/L (U.S. Environmental Protection Agency, 2000b). No invertebrate or fish samples were collected at Willow Pond as part of this study; however, Hillestad and others (1975, p. 140) collected mosquitofish and warmouth in September 1973.

Lake Retta complex

Lake Retta is a palustrine scrub-shrub wetland (table 2)—this wetland type comprises about 4 percent of the freshwater wetlands on Cumberland Island. Lake Retta formed within or adjacent to foredunes that have impeded the natural drainage of surface water and shallow ground water from surrounding areas (fig. 3). Lake Retta is less than 10 ft above sea level and less than 1,500 ft west of the mean high tide, and may be susceptible to the influence of salt aerosols blown by the wind. Hillestad and others (1975, p. 56) stated that open water in Lake Retta probably is maintained by the occasional inundation of seawater that would kill emergent and floating vegetation.

Wetlands within the Lake Retta complex are semi-permanent. Although the surface area of these wetlands varies from year to year, the wetlands are largest during the spring before the period of maximum evapotranspiration and when precipitation is greatest. During this study, the aerial extent of many of the sampled and unsampled wetlands decreased from spring to late summer—with some areas becoming completely dry with no open areas of surface water and remained so throughout the winter. The extent and hydroperiod of these wetlands was greatly diminished during spring and fall sampling in 1999, probably because of drought conditions in the southeastern U.S., before and throughout this study (fig. 6).

The water-surface height of Lake Retta decreased from 0.64 ft in April 1999 to 0.24 ft in October 1999 to below the zero datum by December 1999; the water-surface height was also below the zero datum in March 2000 (Appendix A). The wetted area of Lake Retta was similar in December 1999 and March 2000 but smaller than observed in April 1999; possibly because of the long-term rainfall deficit rather than the most recent monthly rainfall (fig. 6).

Concentrations of many constituents (hardness, Ca, Mg, Na, Br, Cl, PO_4, and tannin and lignin) were lowest in the April 1999 sample when the water level was highest. In December 1999, low water levels, a high rainfall deficit, and evaporation and transpiration likely contributed to high concentrations of SC, Mg, K, Na, Br, Cl, and NO_3. Tannin and lignin concentrations measured at Lake Retta were highest in October 1999, possibly due to decomposition of dead plant material in autumn. Lake Retta did not receive enough rainwater or salt aerosols from Hurricane Floyd to noticeably affect water quality or water levels in the October 1999 sample collected 2 weeks after the hurricane. The relative abundance of major ions in water samples from Lake Retta is described by the Na–Ca–HCO_3–Cl hydrochemical facies. The water sample from Lake Retta Complex south of the foot bridge was the only surface-water sample with the relative abundance of major ions described by the Ca–HCO_3 hydrochemical facies (fig. 7A).

Fifteen taxa of aquatic invertebrates were identified from samples collected from Lake Retta in 1999, including 10 taxa of aquatic insects (table 5). Invertebrate diversity was similar during April when 10 taxa were collected and in December when 9 taxa were collected. All aquatic insects present in Lake Retta were from the order Coleoptera, except for one Odonata and one Hemiptera. Other invertebrates present in Lake Retta included a leech (*Erpobdella puntactata*), a crayfish (*Procambarus* sp.), an unidentified amphipod, and two taxa of snails (*Pseudosuccinea columella* and *Physella* sp).

The only fishes collected in Lake Retta were mosquitofish and sailfin mollys (table 6), both of which are known to be tolerant of seawater and near-anaerobic conditions (Jenkins and Burkhead, 1994). Hillestad and others (1975) reported the presence of sheepshead minnows, striped mullets, and the American eel (*Anguilla rostroda*) in Lake Retta in September 1973.

Beach outflows

Based on field observations, Whitney outflow and Lake Retta outflow were classified as estuarine intertidal emergent wetlands with irregular connections to the ocean. The outflows were not laterally extensive enough in March 1983 source photographs to be classified by NWI photographic interpretation methods. These wetlands are on the ocean side of the island with altitudes near the mean high-tide level, and they share some similarities with tidal creeks that drain estuarine intertidal wetland areas on the eastern side of the island. The beach outflows as observed under drought conditions during this study are similar to ground-water flow through tidal wetlands described by Mitsch and Gosselink (1993, p. 92-94). Beach outflows are unique water bodies on Cumberland Island and are characterized by their small size, irregular connection to the ocean, and influence by fresh ground water. The Whitney outflow and Lake Retta outflow have characteristics that are similar to the dune- and swale-associated wetlands; however, the outflows are much closer to the ocean in foredune beach areas where shallow ground water and overflows from interdunal wetlands contribute to form small bodies of open water.

Hillestad and others (1975), historical maps, and aerial photographs (Lambert, 1992) suggest the existence of surface-water connections between the Lake Retta outflow and the Whitney outflow and their respective upgradient dune-associated wetlands. Hillestad and others (1975, p. 58 and 60) stated that most of the water flowing from the Whitney outflow to the Atlantic Ocean comes from the Sweetwater Lake complex with occasional overflow from Whitney Lake. In February 1999, water from Whitney outflow flowed across the beach to the ocean (Daniel J. Hippe, U.S. Geological Survey, written commun., 2001); however, from March 1999 to July 2000, project staff did not observe water flowing from the outflows. Aerial photographs dating from the 1940's (Lambert, 1992) and staff and visitors' observations suggest that surface flow out of Whitney outflow may be common during wetter periods.

Wave height and high tide are two of several factors that influence wetlands in close proximity to the Atlantic Ocean and for which data were available near Cumberland Island. The closest available data collection sites to Cumberland Island for wave height (fig. 9B) is from Buoy 41008 in the Atlantic Ocean, which is about 52 miles northeast of the

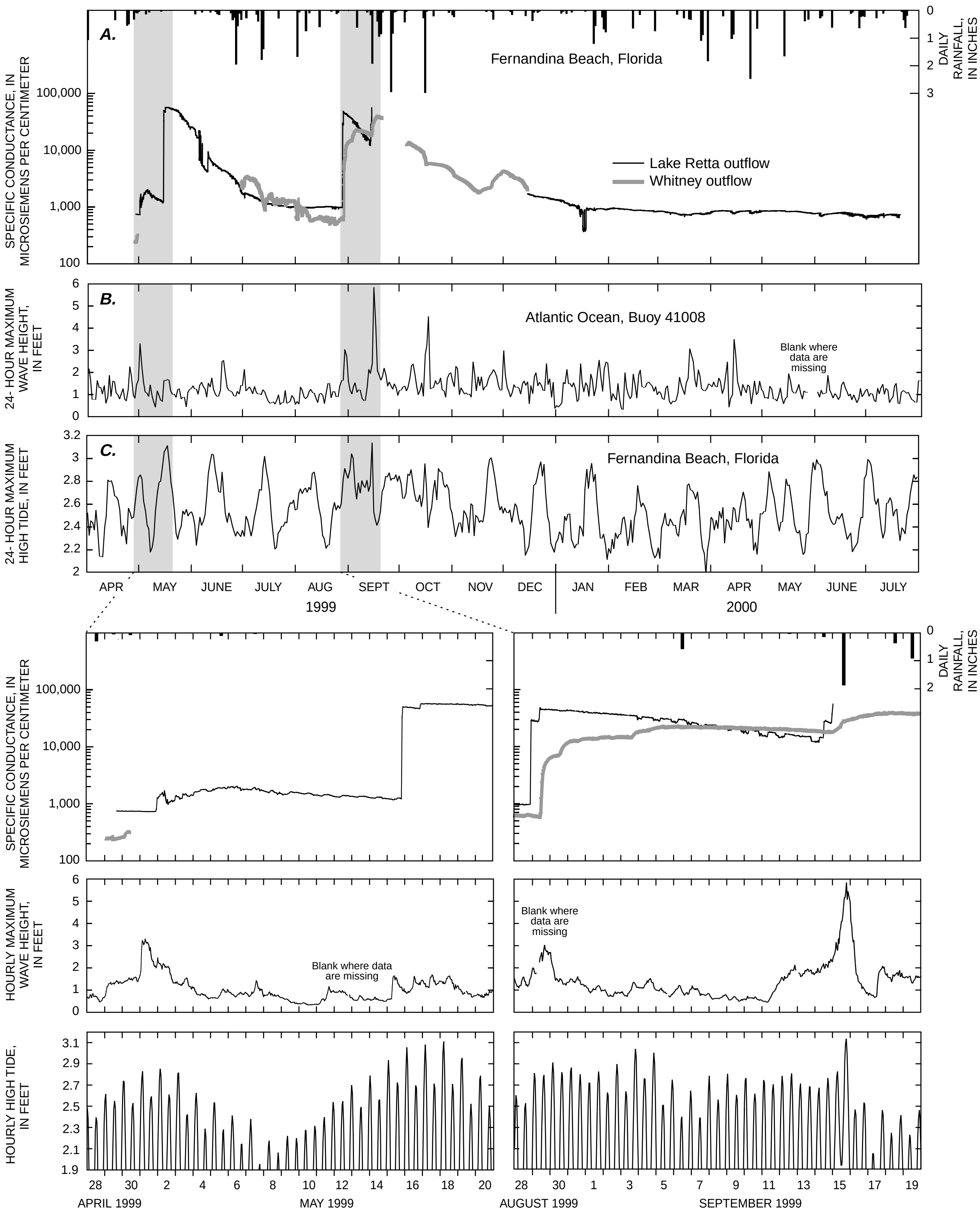


Figure 9. (*A*) Daily rainfall and specific conductance; (*B*) maximum wave height; and (*C*) high tide data collected at or near beach outflows, April 1999 to July 2000. (Data Sources: Lake Retta and Whitney outflows specific conductance, USGS digital data; wave height, National Data Buoy Center, *http://www.ndbc.noaa.gov*, accessed on October 26, 2000; rainfall, National Weather Service, *http://www.ols.nndc.noaa.gov*, accessed on October 25, 2000.)

Lake Retta outflow, and for precipitation and hourly tides (fig. 9A and C, respectively) is from Fernandina Beach, Fla., which is about 11 miles south of the Lake Retta outflow.

Based on SC measurements, the Lake Retta outflow was inundated by seawater during at least three time periods from April 29, 1999, through July 21, 2000 (fig. 9A). For example, from April 30 to May 2, 1999, maximum high tide at Fernandina Beach, Fla., was 2.85 ft, and a storm near Cumberland Island produced a peak wind speed of 3.3 knots and a peak wave height of 3.3 ft at Buoy 41008 (National Data Buoy Center, *http://www.ndbc.noaa.gov*, accessed on October 26, 2000). During this early May storm, SC in Lake Retta outflow increased by less than 1,000 μS/cm (fig. 9A), probably indicating that a few waves spilled seawater into the Lake Retta outflow or that subsurface marine water near the high-tide level contributed to the outflow, but that Lake Retta outflow was not inundated by seawater. In contrast, about 2 weeks later on May 15, 1999, SC in the Lake Retta outflow increased by more than an order of magnitude from 1,200 μS/cm at 7 p.m. to 50,000 μS/cm at 9 p.m. During the storm on May 15, maximum high tide at Fernandina Beach, Fla., was 2.93 ft and maximum wave height measured at Buoy 41008 was only 1.64 ft; however, wind speed peaked at 12.3 knots about 12 to 16 hours before the Lake Retta outflow was inundated. During this mid-May storm, maximum wave heights were lower while wind speeds and high tides were higher than during the early-May storm. Specific examples of combinations of wave height, wind speed, and high-tide levels that have caused inundation of the Lake Retta outflow are not available because wave heights and high tides at the Lake Retta outflow differ from those measured nearby.

The Lake Retta outflow and Whitney outflow were inundated during two storm events in late August to September 1999 (fig. 9). At the Lake Retta outflow, SC increased sharply from 990 μS/cm on August 28, 1999, at 9 p.m. to 49,000 μS/cm on August 29, 1999, at 10 a.m. At the Whitney outflow, SC began increasing 14 hours later and increased more gradually and for a longer period of time. This 14-hour delay in inundation between the Whitney outflow and the Lake Retta outflow perhaps was because the Whitney outflow is more protected by foredunes and is probably at a slightly higher altitude than the Lake Retta outflow. Following the late August inundation and before SC values decreased below 12,000 μS/cm at the outflows, Hurricane Floyd caused SC values to increase to at least 56,000 μS/cm at 12 p.m. on September 15, 1999, at the Lake Retta outflow and to 40,000 μS/cm at 8 a.m. on September 18, 1999, at the Whitney outflow. Unfortunately, but not surprisingly, the storm surge produced by Hurricane Floyd flooded the instrumentation at the Lake Retta outflow and the last SC measurement made during the hurricane was 56,000 μS/cm at 12 p.m. on September 15, 1999. On September 15, 1999, Hurricane Floyd was “abeam of the Florida/Georgia border” (Preliminary report—Hurricane Floyd 7–17 September, 1999, National Hurricane Center, written commun., *http://www.nhc.noaa.gov/1999floyd_text.html*, accessed on July 13, 2001) and produced 1.9 inches of rain about 3 miles south of Cumberland Island. Hurricane Floyd was the largest storm system to pass near Cumberland Island between April 1999 and July 2000; on September 15, 1999, the hurricane produced the highest waves (5.84 ft at 6 p.m.) and the highest wind speeds (24.4 knots at 7 p.m.) measured at Buoy 41008 during the study period (National Data Buoy Center, *http://www.ndbc.noaa.gov*, accessed on December 26, 2000). Waves from Hurricane Floyd eroded several feet of the east side of many foredunes along the Atlantic beaches of Cumberland Island.

During extreme high tides, beach foredune areas including outflows were inundated by seawater forming a haline aquatic system. In contrast, during quiescent periods, the inflow of fresh ground water changed the major-ion chemistry of beach outflows to be more similar to freshwater than seawater (Appendix A). Based on unpublished field measurements collected during this study, SC was higher near the mouth of the Whitney outflow (located on the beach) than toward the inland part of the water body suggesting a ground-water-driven freshwater/saline water gradient within this wetland. No gradient in SC was observed along the length of the Lake Retta outflow wetland area.

Because of equipment malfunctions, SC data were collected at both the Lake Retta and Whitney outflows for only limited intervals during the study period. In general, patterns and timing of SC fluctuations in response to major storms are similar at these two outflows. Periods of high SC measured in the outflows were followed by gradual declines to near levels observed during periods without storms or without higher than normal tides. Large precipitation events coincided with sharper declines of SC at the Whitney outflow; however, SC at the Lake Retta outflow appeared to be less responsive to precipitation events (fig. 9A). More overlap in SC data collected at these two outflows may provide better clues on how SC declines relative to ground-water inflows to the outflow wetland areas.

Constituent concentrations in water samples were similar at the Lake Retta outflow and Whitney outflow (table 4; fig. 7A; Appendix A). Water-quality samples collected at the outflows on October 5, 1999—about 2 weeks after inundation by seawater from Hurricane Floyd—were more similar in composition to seawater than freshwater. Concentrations of SC, Ca, Mg, K, Na, Cl, SO_4, PO_4, Br, and tannin and lignin were about 2 to 10 times higher in these post-hurricane samples than concentrations measured in April and December 1999, and in March 2000. Dissolved oxygen ranged from 7.2 to 9.0 mg/L at the Whitney outflow and from 2.7 to 9.2 mg/L at the Lake Retta outflow, except in measurements collected after Hurricane Floyd when DO was less than 0.5 mg/L. Nitrate concentrations measured in December 1999 samples were 1 mg/L for Lake Retta outflow and 12 mg/L for Whitney outflow, but concentrations were an order of magnitude lower in April and October 1999 samples. A combination of oxidized dead plant material or fecal material from horses could have caused elevated NO_3 concentrations; however, limited data indicate a poor correlation between relatively high NO_3 concentrations and relatively high PO_4 concentrations.

Invertebrate communities of Lake Retta outflow and Whitney outflow were similar, and were composed of 16 and 15 taxa, respectively (table 5). Aquatic insects dominated communities in both outflows, with Coleoptera and Hemiptera being the most common orders collected. Crabs (*Callinectes* sp.) and shrimp (*Penaeu*s sp.) were collected in both outflows, but were not present in upland wetlands sampled on Cumberland Island. Mayflies (*Callibaetis* sp.), a spider (*Tetragnatha* sp.), a giant waterbug (*Belostoma* sp.), and an unidentified species of butterfly (Pyralidae) were collected only at the outflows and appeared to be associated with stands of cattail (*Typha* sp.), lizard’s tail (*Saururus cernuus*), and other emergent vegetation present in these water bodies.

The Whitney outflow and Lake Retta outflow were the most diverse wetlands sampled in terms of number of fish species, with each having six species (table 6). During April, these water bodies were slightly more diverse and were inhabited by five species; whereas—during December only—four species were present. Three species, the sheepshead minnow, the mottled mojarra, and mosquitofish, were present in both spring and fall sampling and appear to be year-round inhabitants of the beach outflows. Striped mullets and sailfin mollys were found in both outflows only during April. The tarpon snook was collected only from the Whitney outflow whereas the striped killifish was collected only from the Lake Retta outflow—both during December 1999.

South End Ponds

South End Ponds are classified as palustrine wetlands with unconsolidated bottoms (table 2), and represent less than 1 percent of the total wetland areas on Cumberland Island. The South End Ponds are semi-permanent water bodies on the southern end of Cumberland Island that are adjacent to salt marshes (fig. 2) and Cumberland Sound (fig. 1). The water body sampled as part of this study was named South End Pond 3 because the pond is believed to be Pond 3 sampled by Kozel (1991, fig. 1; Thomas R. Kozel, Anderson College, written commun., 2001). The presence of small debris dams and rills formed by flowing water between South End Pond 3 and Cumberland Sound following Hurricane Floyd suggests inundation by water from Cumberland Sound during storm surges and periods of higher than normal tides. The height of the water surface of South End Pond 3 was 1.3 ft higher in October after Hurricane Floyd than in April 1999. In April 1999, in addition to the lowest height of the water surface measured during this study, South End Pond 3 also had DO concentrations less than 0.5 mg/L compared to well-oxygenated water in December 1999 and March 2000.

South End Pond 3 had the highest major-ion concentrations of any wetland sampled during this study; these concentrations were similar to or greater than typical seawater (Stumm and Morgan, 1996; fig. 7A). Concentrations of major ions in the South End Pond 3 sample collected in April 1999 (Appendix A) were greater than typical concentrations in seawater and were most likely due to evaporation of seawater. The hydrochemical facies of two South End Pond 3 samples and of seawater are Na–Cl. The similarity of the hydrochemical facies, concentration of major ions and TDS in the South End Pond 3 samples to the relative abundance and concentrations of typical seawater (fig. 7A) suggest that intermittent inundation by seawater and concentration by evapotranspiration are controlling factors in the chemistry of South End Pond 3 water chemistry. Major-ion chemistries of samples collected from shallow wells on the south end of the island (fig. 7B, C) were similar to water from South End Pond 3. Data were not collected as part of this study to determine the degree of interaction between ground water and the South End Ponds.

The highest PO_4 concentration measured on Cumberland Island during this study, 32.6 mg/L, was measured in South End Pond 3 during October 1999, 2 weeks after Hurricane Floyd. The total recoverable Zn concentration was 85 μg/L in the October 1999 sample from South End Pond 3. Using USEPA's conversion factor of 0.946 (U.S. Environmental Protection Agency, 1999, p. 24), 85 μg/L total recoverable Zn converts to 80 μg/L dissolved Zn, which is slightly less than the CCC of 81 μg/L for dissolved Zn in seawater (U.S. Environmental Protection Agency, 1999, p. 7). South End Pond 3 had the highest Mn concentration (51 μg/L) measured in surface-water samples during the study, which slightly exceeds the secondary standard for drinking water of 50 μg/L (U.S. Environmental Protection Agency, 2000b).

In terms of taxa abundance, invertebrate and fish communities of South End Pond 3 were relatively depauperate compared to other wetlands sampled on the island during April and December 1999. Samples collected in April contained only three taxa of invertebrates: water boatmen (corixidae), water scavenger beetles (hydrophilidae), and an unidentified gastropod; whereas samples collected during December contained only two taxa, backswimmers (notonectidae), and aquatic sow bugs (asellidae) (table 5). The low number of aquatic taxa found in South End Pond 3 is probably due to the haline conditions and in April 1999, the very low DO concentration.

Four species of fishes were collected from South End Pond 3 in April and December 1999 samples (table 6). During April, when the measured DO was less than 0.5 mg/L, the fish community of South End Pond 3 was comprised only of mosquitofish and sheepshead minnows; whereas sheepshead minnows, striped mullets, and sailfin mollys were collected during December. One species, the sheepshead minnow, was collected from the South End Pond 3 in April and December. In September 1973, mosquitofish, sheepshead minnows, and sailfin mollys were collected (Hillestad and others, 1975).

GROUND WATER

The surficial and Upper Floridan aquifers (fig. 4) on Cumberland Island are the primary sources of drinking water for residents, park employees, and visitors. Unconfined portions of the surficial aquifer are also important for sustaining freshwater wetland ecosystems on Cumberland Island. Ground-water-level data were collected in May and September 1999 and May 2000 as part of the USGS water-level monitoring program. Ground-water-quality data were collected as part of this study in April 1999 and March 2000. During the 12-month period from April 1999 through March 2000 when ground-water-quality data were collected for this study, rainfall was 12.93 inches below the 30-year average rainfall (fig. 6). Antecedent rainfall conditions were 13.31 inches below normal for the 12-month period prior to ground-water data collection. Wells screened in the surficial aquifer that were sampled for this study have never been used for drinking water. Drinking-water wells in NPS campgrounds that are screened in the surficial aquifer were not sampled because of the logistical difficulty in transporting sampling equipment into the wilderness area. In contrast, all of the wells open to the Upper Floridan aquifer that were sampled are domestic water-supply wells.

Ground-Water Levels

As discussed in the "Ground Water" subsection in the "Introduction" of this report, regional declines in the potentiometric surface of the Upper Floridan aquifer are well documented in many parts of coastal Georgia. Long-term water-level data from several wells near, but not on Cumberland Island, show little to no trend in water levels in the St Marys, Ga.,–Fernandina Beach, Fla., area from 1990 to 1998 (Peck and others, 1999), even though withdrawals in the area increased from 81 Mgal/d to about 88 Mgal/d during the same period (*http://water.usgs.gov/watuse*, accessed on March 2002; R.L. Marella, U.S. Geological Survey, written commun., 2002; Fanning, 1999). Historical ground-water-level measurements (table 3, fig. 10, *http://waterdata.usgs.gov/ga/nwis/nwis*, accessed on March 2002) indicate seasonal and annual variability in water levels in individual wells and among wells on Cumberland Island. It is difficult, however, to make conclusions about trends in water levels on Cumberland Island for wells open to the Upper Floridan aquifer based only on biannual water-level measurements since 1984 and incomplete annual ground-water withdrawal data in the area affected by the Fernandina Beach, Fla.,–St Marys, Ga., cone of depression since 1939 (figs. 5, 10).

Ground-water-level measurements were made one to three times during the study period at 11 wells open to the Upper Floridan aquifer and in 1 well screened in the surficial aquifer at the southern end of Cumberland Island (table 3; fig. 10). Water-level data reported as negative values in table 3 are heads measured above land surface, and represent a point on the potentiometric surface of the confined Upper Floridan aquifer. Measured heads in the

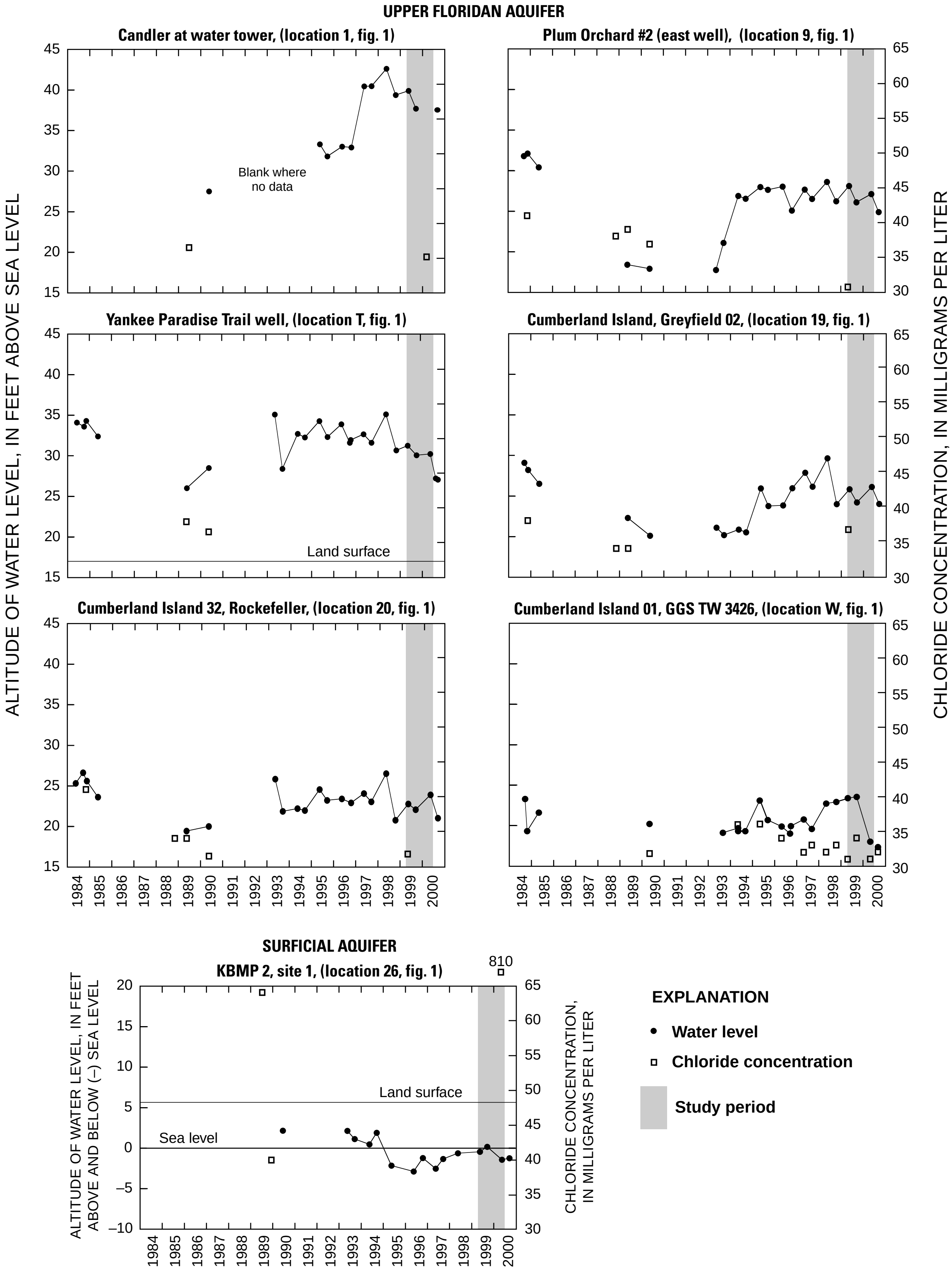


Figure 10. Ground-water levels and chloride concentrations, Cumberland Island, 1984 –2000.

Upper Floridan aquifer ranged from 27.2 to 5.3 ft above land surface on May 3, 1999 (5 days after water-quality samples were collected from five of these wells), from 25.8 to 4.6 ft above land surface on September 27, 1999, and from 23.9 to 1.0 ft above land surface on May 8–10, 2000 (table 3).

Water levels in wells open to the Upper Floridan aquifer are affected by ground-water withdrawals in the measured well, in nearby wells, in the regional pumping center at Fernandina Beach, Fla.,–St Marys, Ga., to the south and west of Cumberland Island, and potentially in the regional pumping center at Brunswick, Ga., to the north. The altitude of the potentiometric surface relative to sea level is estimated by subtracting the water level relative to land surface (accurate to tenths) from the altitude of land surface relative to sea level (accurate to 2.5 ft for altitudes of land surface estimated from topographic maps). The altitude of the potentiometric surface during this study ranged from a maximum of about 40 ft above sea level at the northernmost well measured (Candler at water tower well; location 1, fig. 10) to a minimum of about 18 ft above sea level near the southern end of Cumberland Island (Cumberland Island 01, GGS TW 3426; location W; fig. 10). The Fernandina Beach–St Marys cone of depression in the Upper Floridan aquifer was evidenced by a north-to-south decrease in the altitude of the potentiometric surface of about 16 to 22 ft above sea level during the study period.

Water-level fluctuations in the surficial aquifer are mainly cause by variations in precipitation, evapotranspiration, natural drainage, and tidal fluctuations. Water levels generally rise rapidly during wet periods and decline slowly during dry periods (Cressler and others, 2001, p. 7). KBMP 2, Site 1, a 23-ft-deep well on the southern end of the island, is the only well on the island screened in the surficial aquifer with long-term water-level data available. During the study period, water levels in KBMP 2 ranged from approximately 5.5 to 7.1 ft below land surface (table 3, fig. 10), which is equivalent to 0.2 ft above sea level to 1.4 ft below sea level (fig. 10).

Ground-Water Quality

In general, chemical characteristics of ground water are affected by the initial chemical composition of water entering the aquifer, the composition and solubility of rocks and sediments with which the water comes in contact, and the length of time the water remains in contact with these rocks. On barrier islands, other important factors affecting ground-water quality include the amount and frequency of mixing between freshwater and seawater due to tidal fluctuations, storm surges, recharge conditions, and ground-water pumping. Wells screened in the surficial aquifer that were sampled as part of this study are all monitoring wells or temporary drive points that were never intended to provide drinking water. The quality of water in the surficial aquifer is important, however, because (1) water from the surficial aquifer supplies several campground wells and other low-capacity drinking-water wells, and (2) shallow ground water provides inflow to ponds and lakes; as well as tidal streams and estuaries on the west side of the island and the ocean on the east side of the island. If the potentiometric surface of the Upper Floridan aquifer is drawn down sufficiently by ground-water pumping, then the surficial aquifer may provide limited recharge to the Upper Floridan aquifer.

MCLs were not exceeded in ground-water samples collected from the surficial aquifer during this study (Appendix C) or in samples collected during 1989 from shallow monitoring wells on the southern end of Cumberland Island (Appendix D). Secondary standards for drinking water were commonly exceeded in ground-water samples from the surficial aquifer. Saltwater encroachment into the shallow surficial aquifer at the southern end of Cumberland Island was the primary reason that the secondary standards were commonly exceeded for Cl (250 mg/L), SO_4 (250 mg/L), TDS (500 mg/L), and Mn (50 µg/L) in samples collected in 1989 (Wilson, 1990; Appendix D) and samples collected as part of this study in 2000 (table 7; Appendix C). In 1999-2000, ground-water samples with SO_4 concentrations exceeding the secondary standard of 250 mg/L were 860 mg/L in well KBMP 3 (location 27; fig. 1) and 910 mg/L in well KBMP 5 (location 28) near the southern end of Cumberland Island. These two shallow wells (table 3) also had Cl concentrations of 8,000 and 6,900 mg/L, respectively, indicating mixing with seawater. Well KBMP 6 (location 29) had the highest Cl concentration (16,000 mg/L) measured in ground-water samples during the study, but had SO_4 concentrations less than 0.2 mg/L. In the two shallowest wells at the southern end of Cumberland Island, Cl concentrations increased about an order of magnitude from 40 mg/L in December 1989 to 810 mg/L in March 2000 (KBMP 2, Site 1; location 26; fig. 10) and from 580 mg/L in December 1989 to 6,900 mg/L in March 2000 (KBMP 5, Site 2; location 28).

Table 7. Ranges of selected water-quality constituents in ground water, Cumberland Island and vicinity

[—, information unknown; mg/L, milligrams per liter; μS/cm, microsiemens per centimeter; Ca, calcium; Mg, magnesium; SiO_2, silica dioxide; SO_4, sulfate; Na, sodium; Cl, chloride; N, nitrogen; P, phosphorus; <, less than; >, greater than; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, one or more observation exceeds U.S. Environmental Protection Agency secondary standards for drinking water]

				Observed ranges											
				Field water-quality constituents			Laboratory water-quality constituents								
Location number(s) (fig. 1)	Description of ground water sampled or well identifier	Number of observa-tions or samples	Well depth, feet	Dissolved oxygen, mg/L	pH[1/], field	Specific conduc-tance field, μS/cm	Calcium, dis-solved, mg/L as Ca	Magne-sium, dissolved, mg/L as Mg	Sodium, dis-solved, mg/L as Na	Chloride[1/], dissolved, mg/L as Cl	Silica, dis-solved, mg/L as SiO_2	Sulfate[1/], dis-solved, mg/L as SO_4	Solids, sum of constitu-ents[1/], dis-solved, mg/L	Nitrate[2/], dis-solved, mg/L, as N	Orthophos-phorus, dissolved, mg/L, as P
			72008	00300	00400	00095	00915	00925	00930	00940	00955	00945	70301	00618	00671
Surficial aquifer–Cumberland Island, March 6-8, 2000															
5, 7, 14, 16	shallow ground water near outflows	4	1	<0.5-0.7	5.6-7.2	311-1,670	9.1-93	7-20	31-270	60-320	13-26	5.4-46	160-938	—	—
22, 23, 26, 27, 28, 29	shallow ground water near southern end of Cumberland Island	6	23-132.4	<0.5-0.6	5.9-7.5	412->10,000	66-390	5.7-1,000	14-9,000	21-16,000	7.9-36	<0.2-910	252-14,500	—	—
Upper Floridan aquifer–Cumberland Island, April 27-28, 1999															
1, 10, 20	Upper Floridan aquifer	3	unknown-750	<0.5	6.9-7.4	372-627	70.8-77.0	33.5-36.8	23.1-26.3	31.7-35.3	13.2-16.1	136-152	422-467	0.02-0.1	<0.02
9	Plum Orchard #2 (east well)[3/]	1	600	<0.5	7.0	348	[4/]4.1	[4/]4.3	21.9	30.7	[4/]0.2	[4/]0.4	[4/]82	<0.02	<0.02
19	[3/]Cumberland Island Greyfield 02	1	730	<0.5	7.5	89	50.9	[4/]6.0	16.3	36.7	9.7	[4/]20.4	216	<0.02	0.013
Upper Floridan aquifer–northeastern Florida (Katz, 1992, p. 8 and 13, ground-water basin V)															
Northeastern Florida	Upper Floridan aquifer	[5/]3-48	200-2,026	—	6.6-8.0	—	17-550	6.3-260	2.8-2,200	2.7-3,500	5.55-36	101-7,080	101-7,080	.005-.025	.046-.068

1/Secondary standards for drinking water (U.S. Environmental Protection Agency, 2000b): pH, 6.5–8.5; sulfate, 250 mg/L; chloride, 250 mg/L; total dissolved solids, 500 mg/L.

2/Maximum contaminant level (MCL) for drinking water (U.S. Environmental Protection Agency, 2000a): nitrate, 10 mg/L.

3/These wells are open to the Upper Floridan aquifer based on historical well-construction data, such as well depth, open intervals, and water-levels. However, water-quality data and the age of wells (1904 and 1931, respectively) indicate that water samples analyzed may have included water from the surficial aquifer or rainwater.

4/Concentration measured in water sample from well on Cumberland Island was less than range of concentrations observed in water samples from wells open to the Upper Floridan aquifer in northeastern Florida (Katz, 1992).

[5/]Number of observations is different for different constituents.

In the two shallow drive-point wells sampled near the Whitney outflow (locations 5 and 7), the following concentrations exceeded the secondary standards listed in parenthesis: 5.6 to 6.3 pH (6.5 to 8.5) and 720 to 2,100 mg/L Fe (250 μg/L). Whitney Lake is upgradient from the shallow drive-point wells sampled near the Whitney outflow, and in the surface-water sample collected in March 2000 from Whitney Lake the iron concentration of 760 μg/L also exceeded the secondary standard. In the two shallow drive-point wells sampled near the Lake Retta outflow (locations 14 and 16), the following concentrations exceeded the secondary standards listed in parenthesis: 320 mg/L Cl (250 mg/L), 508 to 1,090 mg/L TDS (500 mg/L), 6,200 mg/L Fe (250 μg/L), and 300 to 660 μg/L Mn (50 μg/L; Appendix C).

The hydrochemical facies of ground water withdrawn from wells screened in the surficial aquifer near the southern end of Cumberland Island was Na–Cl (wells KBMP 1-6; sites 1 and 2; locations 26-29, D, and E), with the exception of two samples collected in 1989 from the shallowest well (well KBMP 1, location 26) in site 1 on the southeastern end of the island (fig. 7B, C). The range of TDS concentrations was from 440 to 31,500 mg/L and the Na–Cl hydrochemical facies in these wells indicate that brackish and marine waters influence shallow ground waters in areas adjacent to Cumberland Sound at the southern end of Cumberland Island. The hydrochemical facies of ground water withdrawn from four of five wells (wells KBMP 7 and 9-11; site 3; locations A-C and 23) screened in the surficial aquifer northeast of Dungeness Ruins (fig. 1) were either Ca–Cl or Ca–HCO_3 (fig. 7B, C). TDS concentrations in water from wells at site 3 (345 to 1,590 mg/L) are one to two orders of magnitude smaller than concentrations measured in water from sites 1 and 2 adjacent to Cumberland Sound; however, TDS still routinely exceeds the secondary standard for drinking water of 500 mg/L (U.S. Environmental Protection Agency, 2000b).

No exceedances of National Primary or Secondary Drinking-Water Regulations were measured in samples collected in 1999 from five domestic water-supply wells open to the Upper Floridan aquifer. Although the secondary standard of 500 mg/L TDS was not exceeded, three of five ground-water samples collected as a part of this study from the Upper Floridan aquifer had TDS concentrations greater than 400 mg/L TDS (Appendix C). In samples collected from 1994-2000 from Cumberland Island well 01 (location W), which is open the Upper Floridan aquifer, TDS concentrations ranged from 484 to 538 mg/L with 9 of 11 samples exceeding the secondary standard of 500 mg/L TDS (Appendix E). Fecal-coliform bacteria were not detected in 1999 in samples collected from two domestic water-supply wells sampled that are open to the Upper Floridan aquifer.

The Ca–Mg–HCO_3–SO_4 hydrochemical facies characterizes ground-water samples collected from the following wells open to the Upper Floridan aquifer on Cumberland Island: Candler (location 1); Reddick (location 10); Cumberland Island well 32, Rockefeller (location 20; fig. 7B; Appendix C); and Cumberland Island 01, GGS TW 3426 (location W) wells (fig. 7C; Appendix E). TDS concentrations in samples collected from these four wells range from 422 to 538 mg/L; water samples from these wells have typical Upper Floridan aquifer chemistry, indicating no mixing with seawater (Appendix C, E).

Plum Orchard #2 well (location 9) has a reported well depth of 600 ft and measured depth to water of 12 to 14 ft above land surface during the study period, indicating that this well is open to the Upper Floridan aquifer. However, extremely low concentrations of TDS (82 mg/L), SO_4 (0.4 mg/L), hardness (27.9 mg/L), Ca (4.1 mg/L), Mg (4.29 mg/L), ANC (29 mg/L), SiO_2 (0.2 mg/L) (Appendix C), and the age of the well (constructed in 1904) indicate that the water sampled from this well is not likely representative of water-quality conditions in the Upper Floridan aquifer. In addition to this ground-water sample having much lower concentrations of several ions compared to ground-water samples collected from five other Upper Floridan aquifer wells on Cumberland Island (Appendix C, E), the sample also had lower concentrations of Ca, Mg, SiO_2, SO_4, and TDS than were reported for wells open to the Upper Floridan aquifer in a similar hydrogeologic setting in northeast Florida (Katz, 1992, p. 8 and 13; table 7). Sprinkle (1989, p. I27 and table 5) lists several scenarios where water sampled from wells open to the Upper Floridan aquifer is a mixture of water from the most permeable zones the wells are open to, including overlying surficial aquifers. Although Plum Orchard #2 well still flows at land surface, a pump is currently installed in the well to provide sufficient quantity and pressure of water. Sodium, Cl, and hydrogen sulfide in the ground water may have contributed to corrosion of the almost 100-year-old well casing. If the casing is not intact near permeable zones in the surficial aquifer, then the pump may withdraw water from shallow permeable zones near the depth where the pump is set. The relative abundance of major ions in the ground-water sample from the Plum Orchard #2 well (location 9) is described by the Na–Cl hydrochemical facies (fig. 7B).

Because the Plum Orchard #2 well is used for drinking water, it should be emphasized that although the major-ion chemistry indicates the casing may not be intact, all concentrations of water-quality constituents were less than National Primary and Secondary Drinking-Water Regulations (U.S. Environmental Protection Agency, 2000a, b). In light of the water-quality conditions measured in samples collected from this well, and the typical age of many wells on Cumberland Island, it would be prudent to use geophysical logging techniques such as televiewer and fluid conductivity to verify well depth and construction information, and to examine the integrity of well casings prior to sampling for the purpose of documenting water-quality trends in the Upper Floridan aquifer underlying Cumberland Island.

The relative abundance of major ions in the ground-water sample collected from the Cumberland Island Greyfield 02 well (location 19) is described by the Ca–HCO_3 hydrochemical facies (fig. 7B). This water sample had low SC (89 μS/cm) and moderately low concentrations of Ca (50.9 mg/L), Mg (5.96 mg/L), SO_4 (20.4), and TDS (216 mg/L) concentrations compared to the three Upper Floridan wells having a Ca–Mg–HCO_3–SO_4 hydrochemical facies and sampled as a part of this study and compared to the range of constituent concentrations reported in water from wells open to the Upper Floridan aquifer in northeast Florida (table 7; Katz, 1992). As with the Plum Orchard #2 well, the Cumberland Island Greyfield 02 well is old (installed in 1931) and the major-ion chemistry and TDS of its water may be indicative of Upper Floridan water mixing with surficial aquifer water, possibly as a result of corroded or deteriorated casing. Although this water sample had somewhat atypical water-quality characteristics compared to a representative sample from the Upper Floridan aquifer, all measured concentrations of water-quality constituents were less than National Primary and Secondary Drinking-Water Regulations (U.S. Environmental Protection Agency, 2000a, b).

Based on ground-water samples collected either once or twice per year from 1994–2000, the hydrochemical facies of water from Cumberland Island well 01 (location W), which is 645-ft-deep and open to the Upper Floridan aquifer, has consistently been Ca–Mg–HCO_3–SO_4 (fig. 7C). In a highly confined part of the Upper Floridan aquifer such as underlies Cumberland Island, the major-ion concentrations and the hydrochemical facies of ground water withdrawn from a given well are expected to remain fairly constant through time unless outside influences affect water quality, such as surface contamination from faulty well construction, large drawdowns in the potentiometric surface that change source areas for the well, or saltwater encroachment.

Clarke and others (1990, p. 48) stated that Cl concentrations in the Upper Floridan aquifer in most coastal areas of Georgia are less than 40 mg/L. Chloride concentrations in the Upper Floridan aquifer underlying Cumberland Island ranged from about 31 to 37 mg/L based on five wells sampled in April 1999 for this study (fig. 10, Appendix C) and on the Cumberland Island 01 well sampled from 1994 to 2000 as part of the St. Johns River Water Management District water-quality monitoring program (fig. 10; Appendix E). These Cl concentration data and limited evidence related to the depth and location of the freshwater/saltwater interface (Jones and others, 2002; W.F. Falls, U.S. Geological Survey, written commun., 2001) indicate that saltwater intrusion is currently not a problem in the Upper Floridan aquifer at Cumberland Island. However, wells open to the Lower Floridan aquifer (stratigraphically beneath the Upper Floridan aquifer (fig. 4)) in parts of coastal Georgia (Clarke and others, 1990) and northeastern Florida (Brown, 1984; Spechler, 1994) have Cl concentrations greater than 250 mg/L—the secondary standard for drinking water (U.S. Environmental Protection Agency, 2000b). Periodic monitoring of Cl concentrations in water from wells open to the Upper Floridan aquifer and developing a better understanding of the freshwater/saltwater interface below and east of Cumberland Island would provide early warning of potential future saltwater intrusion.

SUMMARY

In 1999-2000, the USGS conducted a study in cooperation with the National Park Service to assess the surface- and ground-water quality along with the fish and invertebrate communities in upland wetlands of the Cumberland Island National Seashore, Ga. As part of this study, historical ground-water, surface-water, and ecological studies conducted on Cumberland Island were summarized. Surface-water samples were collected quarterly from April 1999 to March 2000 from six wetlands in the upland areas of Cumberland Island. During this 12-month period when water-quality samples were collected, rainfall was 12.93 inches below 30-year average rainfall and antecedent rainfall conditions were 13.31 inches below normal for the 12-month period prior to sample collection for this study. Surface-water samples collected from these areas were analyzed for major ions, nutrients, trace elements, and field measurements (specific conductance, pH, temperature, dissolved oxygen, alkalinity, tannin and lignin, and turbidity). In addition, continuously recorded temperature and specific conductance data were collected from two wetland areas located near the mean high tide mark on the Atlantic beaches. Fish and invertebrate communities were sampled from six wetland areas during April and December 1999. Ground-water samples were collected from the surficial and Upper Floridan aquifers at 11 permanent and 4 temporary drive-point wells. Ground-water samples were analyzed for major ions, nutrients, trace elements, and field measurements (specific conductance, pH, temperature, dissolved oxygen, and alkalinity).

Wetlands on Cumberland Island vary from permanent, freshwater systems with minor influence from the ocean; to permanent, high-salinity systems with direct connections to the Atlantic Ocean or Cumberland Sound during most high tides; to temporary ponds of varying salinity that are connected to the ocean or sound only during spring tides or storms. Water levels and salinity fluctuate seasonally in response to rainfall, evapotranspiration, and, in wetlands with periodic connections to the ocean or sound, to tides. Major differences in barrier island wetlands are thought to be primarily due to their varying stages of successional development, hydroperiod, degree of solar exposure, proximity to salt aerosols, and direct inflow from seawater. Differences in aquatic invertebrate and fish communities in freshwater habitats on Cumberland Island are influenced by a number of factors including hydroperiod, water-quality conditions, and presence or type of aquatic vegetation.

Water bodies that are more frequently inundated by saline or brackish water from the Atlantic Ocean or Cumberland Sound—such as the beach outflows and South End Pond 3—tend to have water compositions more similar to seawater (with high concentrations of total dissolved solids, sodium, chloride, and sulfate) than water bodies where the primary oceanic influence is from salt aerosols. Although surface waters on Cumberland Island are not used as sources for drinking water, exceedances of U.S. Environmental Protection Agency Secondary Drinking-Water Regulations were noted for comparative purposes. A nitrate concentration of 12 milligrams per liter in one sample from Whitney outflow was the only exceedance of a maximum contaminant level. In 26 surface-water samples, secondary standards were exceeded for the following constituents: pH (10 exceedances), chloride (8), sulfate (5), total dissolved solids (4), iron (2), fluoride (1), and manganese (1). The relative abundance of major ions and total-dissolved-solids concentrations in surface-water samples collected from water bodies on Cumberland Island provide some insight into potential sources of water and influences on water quality. Major-ion chemistries of water samples from Whitney Lake, Willow Pond, and South End Pond 3 were sodium-chloride dominated, probably indicating influence from direct inundation of marine waters or input from salt aerosol. The remaining wetlands sampled had relatively low total-dissolved-solids concentrations and mixed major-ion chemistries—North Cut Pond 2A was magnesium–sodium–chloride–sulfate dominated and Lake Retta and the two beach outflows were sodium–calcium–bicarbonate–chloride dominated. The higher percentage of calcium and bicarbonate in surface waters and relatively low total-dissolved-solids concentrations suggest a greater proportion of the water originates from ground-water discharge. In contrast, the major-ion chemistries of wetlands with a higher percentage of sodium and chloride are probably more directly influenced by the ocean via inundation, input from salt aerosol, or rainwater.

Aquatic insects whose life cycles and behavioral adaptations allow them to inhabit wetlands characterized by a range of hydroperiods, water-quality, and habitat conditions dominated aquatic-invertebrate communities in upland wetlands of Cumberland Island. Taxa of marine invertebrates—such as shrimp and crabs—were present along with aquatic insects typically associated with freshwater in unique wetlands in foredune areas adjacent to the Atlantic Ocean. The richest invertebrate communities were present in aquatic and emergent vegetation of Whitney Lake, the largest freshwater body located on any of Georgia's barrier islands.

Mosquitofish were collected in all six waterbodies sampled on Cumberland Island and sailfin mollys were collected in four of these water bodies. These two species were also the most abundant fishes in the water bodies sampled. Mosquitofish and sailfin mollys tolerate highly variable water-quality conditions and bear their young live, which allows them to quickly populate water bodies having short or variable hydroperiods. The most diverse wetland areas in terms of fish communities were the beach outflows—dynamic wetland areas located in foredunes and periodically inundated by seawater but otherwise sustained by discharges of fresh ground water. Fishes inhabiting beach outflows consisted of species able to tolerate fresh- to brackish-water conditions such as sheepshead minnows, mosquitofish, and striped mullets, as well as species typically associated with marine waters such as juvenile tarpon snook and mottled mojarras.

No exceedances of geometric-mean enterococci standards were observed in samples collected from the near-shore Atlantic Ocean, and fecal-coliform bacteria were not detected in the two domestic water-supply wells sampled that are open to the Upper Floridan aquifer. However, wildlife and feral animals on Cumberland Island are nonpoint sources of fecal material that have the potential to cause elevated indicator-bacteria concentrations and may contribute to high nutrient concentrations in small wetlands. Point and nonpoint sources of indicator bacteria to seawater from areas north of Cumberland Island are another potential source of indicator bacteria along the Atlantic beaches.

Cumberland Island is within the cone of depression associated with large withdrawals for industrial use that have occurred since 1939 in Fernandina Beach, Fla. and in St Marys, Ga. In 1999, the potentiometric surface of the Upper Floridan aquifer ranged from a maximum of about 40 feet above sea level at the northern most well measured to a minimum of about 18 feet above sea level near the southern end of Cumberland Island. Long-term water-level data from several wells near, but not on Cumberland Island, show little to no trend in water levels in the Fernandina Beach, Fla.,–St Marys, Ga., area from 1990 to 1998, even though withdrawals in the area increased from 81 Mgal/d to about 88 Mgal/d during the same period. Limited ground-water-level measurements in wells on Cumberland Island indicate seasonal and annual variability in water levels; however, water-level data are not sufficient to make conclusions about trends in water levels on Cumberland Island during the last decade.

There were no exceedances of U.S. Environmental Protection Agency National Primary or Secondary Drinking-Water Regulations in five domestic water-supply wells open to the Upper Floridan aquifer, which were sampled in 1999 as part of this study. In 1994-2000, the secondary standard of 500 mg/L total dissolved solids was exceeded in 9 of 11 samples collected from a well open to the Upper Floridan aquifer. Because well casings may not be intact in some wells installed on Cumberland Island in the early 1900's into the Upper Floridan aquifer, geophysical logging techniques could be used to verify well depth and the integrity of well casings before selecting wells to sample to document water quality.

Chloride concentrations in the Upper Floridan aquifer underlying Cumberland Island ranged from about 31 to 37 mg/L during 1994 to 2000. These Cl concentration data and limited evidence related to the depth and location of the freshwater/saltwater interface indicate that saltwater intrusion is currently not a problem in the Upper Floridan aquifer at Cumberland Island. Periodic monitoring of Cl concentrations in water from wells open to the Upper Floridan aquifer and developing a better understanding of the freshwater/saltwater interface below and east of Cumberland Island would provide early warning of potential future saltwater intrusion.

Although the surficial aquifer does not provide as much drinking water on Cumberland Island as the Upper Floridan aquifer, the water quality of the surficial aquifer is important. Saltwater intrusion into the shallow surficial aquifer at the southern end of Cumberland Island is the primary reason for exceedances of the secondary standards for chloride, sulfate, total dissolved solids, and manganese. In ground-water samples collected 1 foot below land surface near Whitney and Lake Retta outflows, secondary standards of pH, chloride, total dissolved solids, iron, and manganese were exceeded.

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GLOSSARY

Aquatic bed–A wetland class that includes wetlands and deepwater habitats dominated by plants that grow principally on or below the surface of the water for most of the growing season in most years. Water regimes include subtidal, irregularly exposed, regularly flooded, permanently flooded, intermittently exposed, semipermanently flooded, and seasonally flooded. Aquatic beds represent a diverse group of plant communities that requires surface water for optimum growth and reproduction. The plants are either attached to the substrate or float freely in the water above the bottom or on the surface (Cowardin and others, 1979, p. 15).

Beach–A gently sloping zone, typically with a concave profile, of unconsolidated material extending landward from the low-water line to the place where there is a definite change in material or physiographic form or to the line of permanent vegetation. A shore of a body of water formed and washed by waves or tides, usually covered by sand or gravel (National Soil Survey Center, 2001, p. 10).

Brackish–Marine and estuarine waters with mixohaline salinity; the term should not be applied to inland waters (Cowardin and others, 1979, p. 40).

Broad-leaved deciduous–A wetland subclass in palustrine and intertidal estuarine systems. Dominant trees typical of broad-leaved deciduous wetlands are most common in the southern and eastern U.S. Wetlands in this subclass generally occur in mineral soils or highly decomposed organic soils (Cowardin and others, 1979, p. 20-21).

Broad-leaved evergreen–A wetland subclass in palustrine and intertidal estuarine systems. In the estuarine system, broad-leaved evergreen species are dominated by mangroves, which are adapted to varying levels of salinity. In the palustrine system, the broad-leaved evergreen species are typically found in organic soils (Cowardin and others, 1979, p. 20-21).

Criterion Continuous Concentration (CCC)–An estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect (U.S. Environmental Protection Agency, 1999, p. 21).

Deepwater habitats–Permanently flooded deepwater areas, generally deeper than 6 feet (Tiner, 1984, p. 3).

Depauperate–Including few kinds of organisms, used to describe floras and faunas.

Depression–Any relatively sunken part of the Earth's surface; especially a low-lying area surrounded by higher ground (National Soil Survey Center, 2001, p. 24).

Drive-point well–A temporary, hand-driven, shallow well used for measuring water levels and sampling ground water.

Dune–A low mound, ridge, bank or hill of loose, windblown, subaerially deposited granular material (generally sand), either barren and capable of movement from place to place, or covered and stabilized with vegetation, but retaining its characteristic shape (National Soil Survey Center, 2001, p. 27).

Emergent–A wetland class characterized by erect, rooted, herbaceous hydrophytes, excluding mosses and lichens. This vegetation is present for most of the growing season in most years. Perennial plants usually dominate these wetlands. All water regimes are included except subtidal and irregularly exposed (Cowardin and others, 1979, p. 19).

Estuarine–A system of wetlands that includes deepwater tidal habitats and adjacent tidal wetlands that are usually semi enclosed by land but have open, partly obstructed or sporadic access to the open ocean and in which seawater is at least periodically diluted by freshwater runoff from the land (Cowardin and others, 1979, p. 4).

Euhaline–Water-chemistry modifier used to describe water containing ocean-derived salts and which has specific conductances ranging from 45,000 to 60,000 µS/cm (Cowardin and others, 1979, p. 22 and 30).

Facies–Geologic term used to describe observable attributes of a rock or stratigraphic unit (see hydrochemical facies).

Floating bed–A subset of aquatic bed wetland class. Beds of floating vascular plants occur mainly in the lacustrine, palustrine, and riverine systems and in the fresher waters of the estuarine system. The plants float freely either in the water or on its surface (Cowardin and others, 1979, p. 15-16).

Foredune–A coastal dune or dune ridge oriented parallel to the shoreline, occurring at the landward margin of the beach, along the shoreward face of a beach ridge, or at the landward limit of the highest tide, or more or less stabilized by vegetation (National Soil Survey Center, 2001, p. 35).

Forested wetland–A wetland class characterized by woody vegetation 20 feet (6 meters) or taller. All water regimes are included except subtidal (Cowardin and others, 1979, p. 20).

Freshwater–Water-chemistry modifier used to describe water with salinity less than 0.5 parts per thousand dissolved salts (specific conductances less than 800 µS/cm; Cowardin and others, 1979, p. 30 and 40).

Geometric mean–Nth root of the product of a series of N terms. For example, the geometric mean of 2 and 18 is 6—the square root of 36.

Haline–Water-chemistry modifier used to describe water dominated by ocean salts as opposed to salts of terrestrial origin (see saline; modified from Cowardin and others, 1979, p. 40).

Hydrochemical facies–Term adapted from geochemistry and used to describe dominant cation and anion concentrations in water based on subdivisions in trilinear diagram; facies reflect the response of chemical processes operating within the lithologic framework and also the pattern of flow of water (Back, 1966, p. A1).

Hydroperiod–The seasonal pattern of the water level of a wetland. It defines the rise and fall of a wetland's surface and subsurface water. The hydroperiod is an integration of all inflows and outflows of water, but it is also influenced by physical features of the terrain and by proximity to other bodies of water (Mitsch and Gosselink, 1993, p. 72; Cowardin and others, 1979).

Hydrophytes–Any plant growing in water or on a substrate that is at least periodically deficient in oxygen because of excessive water content (Cowardin and others, 1979, p. 40).

Interdune–The relatively flat surface, whether sand free or sand covered, between dunes (modified from National Soil Survey Center, 2001, p. 44).

Intertidal–A subsystem of marine and estuarine systems where the substrate is exposed and flooded by tides; includes the associated splash zone (Cowardin and others, 1979, p. 4 and 7).

Irregularly flooded–A water-regime modifier used when tidal water floods the land surface less often than daily (Cowardin and others, 1979, p. 21).

Lentic–Of or pertaining to still waters such as lakes and ponds (Parker, 1989).

Lignin–A recalcitrant and complex structural polymer found in plant cell walls. Lignin can be found in surface water when vegetation decomposes (Thurman, 1985).

Macrophytes–Plants that are large enough to be visible without the aid of optical magnification; term is often used to describe plants found in the aquatic environment (Parker, 1989).

Marine–A system of wetlands that includes the open ocean overlying the continental shelf and its associated high-energy coastline. Marine habitats are exposed to the waves and currents of the open ocean and the water regimes are determined primarily by the ebb and flow of ocean tides. Salinities exceed 30 parts per thousand, with little or no dilution except outside the mouths of estuaries (Cowardin and others, 1979, p. 4).

Maximum Contaminant Level (MCL)–The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to Maximum Contaminant Level Goals as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards (U.S. Environmental Protection Agency, 2000a). MCL was formerly called primary maximum contaminant level (PMCL).

Mixohaline–Water-chemistry modifier used to describe waters with salinity of 0.5 to 30 parts per thousand (specific conductances range from 800 to 45,000 µS/cm), due to ocean-derived salts. The term is roughly equivalent to brackish (Cowardin and others, 1979, p. 22, 30, and 41).

National Primary Drinking-Water Regulations (*NPDRWs or primary standards*)–Legally enforceable standards that apply to public water systems. Primary standards protect public health by limiting the levels of contaminants in drinking water (U.S. Environmental Protection Agency, 2000a).

National Secondary Drinking-Water Regulations (*NSDRWs or secondary standards*)–Non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, color) in drinking water. USEPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards (U.S. Environmental Protection Agency, 2000b). Secondary standard was formerly called secondary maximum contaminant level (SMCL).

Palustrine–A system of wetlands that includes all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is less than 0.5 parts per thousand. Also includes wetlands lacking such vegetation, but with the following characteristics: (1) area less than 20 acres; (2) lack of active wave formed shore; (3) water depth less than 7 feet (2 meters) and; (4) salinity from ocean-derived salts less than 0.5 parts per thousand (Cowardin and others, 1979, p. 10).

Permanently flooded–A water-regime modifier used when nontidal water covers the land surface throughout the year in all years (Cowardin and others, 1979, p. 22).

Persistent–A subclass of emergent wetlands dominated by species that normally remain standing at least until the beginning of the next growing season. This subclass is found only in the estuarine and palustrine systems (Cowardin and others, 1979, p. 20).

Polyhaline–Water-chemistry modifier used to describe waters with salinity of 18 to 30 parts per thousand (specific conductances range from 30,000 to 45,000 μS/cm), due to ocean-derived salts (Cowardin and others, 1979, p. 30 and 41).

Primary standards–see National Primary Drinking-Water Regulations and Maximum Contaminant Level.

Regularly flooded–A water-regime modifier used when tidal water alternately floods and exposes the land surface at least once daily (Cowardin and others, 1979, p. 21).

Saline–A general term used to describe waters containing various dissolved salts; wetlands classification (Cowardin and others, 1979) restricts the use of saline to describe inland waters where ratios of salts often vary (see haline; modified from Cowardin and others, 1979, p. 41).

Salinity–The total amount of solid salt material in grams contained in 1 kilogram of water when all the carbonate has been converted to oxide, the bromine and iodine are replaced by chlorine, and all of the organic matter is completely oxidized (Cowardin and others, 1979, p. 41).

Scrub-shrub wetland–A wetland class that includes areas dominated by woody vegetation less than 20 feet tall. Includes all water regimes except subtidal (Cowardin and others, 1979, p. 20).

Seasonally flooded–A water-regime modifier used when nontidal surface water is present for extended periods especially early in the growing season, but is absent by the end of the season in most years. When surface water is absent, the water table is often near the land surface (Cowardin and others, 1979, p. 22).

Seawater–Water derived from an ocean or estuary (Parker, 1989). Seawater typically contains dissolved salts dominated by Cl, Na, SO_4, Mg, Ca, and K (Stumm and Morgan, 1996, p. 895).

Secondary standards–see National Secondary Drinking-Water Regulations.

Semipermanently flooded–A water-regime modifier used when nontidal surface water persists throughout the growing season in most years. When surface water is absent, the water table is usually at or very near the land surface (Cowardin and others, 1979, p. 22).

Specific conductance–The reciprocal of the electrical resistance of a one-centimeter cube of a material at 25 °C. The specific conductivity of water, or its ability to conduct an electric current, is related to the total dissolved ionic solids (McCutcheon and others, 1992, p. 11.38).

Spring tides–Tides of increasing magnitude that occur about every two weeks when the moon is new or full (Parker, 1989).

Subtidal–A subsystem of marine and estuarine systems and a water-regime modifier used when the substrate is continuously submerged (modified from Cowardin and others, 1979, p. 4, 7, and 21).

Swale–A long, narrow, generally shallow trough-like depression between two beach ridges that is aligned roughly parallel to the coast (interdune is preferred term; National Soil Survey Center, 2001, p. 83).

Tannin–A diverse group of water-soluble phenolic compounds that have the ability to bind and precipitate proteins. Tannin are contained in different parts of plants and can be found in surface waters during the decomposition of plant matter (Thurman, 1985).

Tannin and lignin (method 8193)–A field method used to measure concentrations of all hydroxylated aromatic compounds present in water samples which includes tannin, lignin, phenol, and cresol. Method 8193 provides an estimate of the amount of decomposing vegetation by-products present in a sample or water body but can have interference from ferrous iron and sulfide (Hach Company, 1997).

Tidal–A water-regime modifier used when oceanic tides largely determine the water regime (Cowardin and others, 1979, p. 21).

Unconsolidated bottom–A wetlands class that includes all wetland and deepwater habitats with at least 25 percent cover of particles smaller than stones, and a vegetative cover less than 30 percent. Water regimes are restricted to subtidal, permanently flooded, intermittently exposed, and semi-permanently flooded (Cowardin and others, 1979, p. 14).

Unconsolidated shore–A wetland class that includes all wetland habitats having three characteristics: (1) unconsolidated substrates with less than 75 percent aerial cover of stones, boulders, or bedrock; (2) less than 30 percent aerial cover of vegetation other than pioneering plants; and (3) any of the following water regimes: irregularly exposed, regularly flooded, irregularly flooded, seasonally flooded, temporarily flooded, intermittently flooded, seasonally flooded, temporarily flooded, intermittently flooded, saturated, or artificially flooded (Cowardin and others, 1979, p. 18).

Upland–An informal term for the higher ground of a region (modified from National Soil Survey Center, 2001, p. 89); land composed of xeric terrestrial habitats that do not have any of the defining characteristics of wetlands.

Water-chemistry modifiers–Terms used to describe salinity class for all wetland habitats and pH levels for freshwater habitats (modified from Cowardin and others, 1979, p. 22).

Water-regime modifiers–Terms used to describe the duration and timing of surface inundation, both yearly and long-term (Cowardin and others, 1979, p. 21).

Wetlands–Lands that are transitional between terrestrial and aquatic wetlands where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification, wetlands must have one or more of the following three attributes: 1) at least periodically, the land supports predominantly hydrophytes; 2) the substrate is predominantly undrained hydric soil; and 3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year (Cowardin and others, 1979, p. 3).

APPENDIX A.—SURFACE-WATER-QUALITY DATA, CUMBERLAND ISLAND, APRIL 1999 THROUGH MARCH 2000

Appendix A. Surface-water-quality data, Cumberland Island, April 1999 through March 2000

[—, data not collected; do., ditto; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; ° C, degrees Celsius; mm, millimeter; E, estimated; <, less than; >, greater than; M, presence of material verified, but not quantified; As, arsenic; ANC, acid neutralizing capacity; Br, bromide; $CaCO_3$, calcium carbonate; Ca, calcium; Cd, cadmium; Cl, chloride; Cr, chromium; Cu, copper; Fe, iron; F, fluoride; HCO_3, bicarbonate; Hg, mercury; K, potassium; Mg, magnesium; Mn, manganese; N, nitrogen; Na, sodium; Ni, nickel; NTU, nephelometric turbidity units; P, phosphorus; Pb, lead; SiO_2, silica dioxide; SO_4, sulfate; Zn, zinc; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, exceeds U.S. Environmental Protection Agency secondary standards for drinking water; darker shading, exceeds U.S. Environmental Protection Agency maximum contaminant level (MCL) for drinking water; all data in this appendix are available online at *http://waterdata.usgs.gov/ga/nwis*]

Location number (fig. 1)	Site name	Date	Time	Agency analyzing sample[1/]	Gage height, feet	Turbidity, field, NTU	Barometric pressure, mm of Hg	Dissolved oxygen	
								mg/L	Percent saturation[3/]
				00028	00065	61028	00025	00300	00301
2	North Cut Pond 2A	04-27-99	1100	1028	1.36	5.2	760	6.8	82
2	do.	10-05-99	0915	1028	1.53	1.6	764	1.7	20
2	do.	12-14-99	1400	1028	.06	47	763	5.2	57
4	Whitney Lake	04-27-99	1330	1028	1.20	6.3	760	3.1	33
4	do.	10-06-99	0930	1028	.77	32	766	2.8	33
4	do.	12-14-99	1530	1028	.84	7.1	763	6.8	72
4	do.	03-08-00	1300	81213	.74	17	773	5.7	61
6	Whitney outflow	04-27-99	1515	1028	1.00	6.2	760	7.2	95
6	do.	10-05-99	1230	1028	1.70	6.9	765	<.5	—
6	do.	12-15-99	1245	1028	.76	17	769	8.0	83
6	do.	03-07-00	1215	81213	.28	50	776	9.0	100
11	Willow Pond	03-08-00	1015	81213	—	38	773	2.0	20
12	Lake Retta complex at foot bridge on Willow Pond Trail	10-06-99	1125	1028	—	130	766	1.0	12
13	Lake Retta complex 420 feet south of foot bridge	04-29-99	1130	1028	—	12	763	3.4	37
15	Lake Retta	04-28-99	1050	1028	.64	5.1	780	7.5	93
15	do.	10-06-99	1145	1028	.24	4.8	766	1.5	18
15	do.	12-15-99	0945	1028	<.0	1.3	769	2.0	18
15	do.	03-07-00	1030	81213	<.0	2.0	773	4.2	41
17	Lake Retta outflow	04-28-99	0900	1028	1.55	5.9	780	2.7	32
17	do.	10-05-99	1345	1028	2.51	12	765	<.5	—
17	do.	12-15-99	1545	1028	1.20	46	769	3.8	39
17	do.	03-07-00	1415	81213	.83	20	774	9.2	102
25	South End Pond 3	04-27-99	1520	1028	.47	320	763	<.5	—
25	do.	10-06-99	1400	1028	1.77	4.1	764	—	—
25	do.	12-16-99	0915	1028	1.19	42	770	8.2	93
25	do.	03-06-00	1400	81213	.90	39	771	9.3	135

[1/]Agency analyzing sample: 1028, U.S. Geological Survey, Georgia District Laboratory; 81213, U.S. Geological Survey, Ocala, Florida Laboratory.

[2/]Secondary standards for drinking water (U.S. Environmental Protection Agency, 2000b): total dissolved solids, 500 mg/L; pH, 6.5 to 8.5; chloride, 250 mg/L; fluoride, 2 mg/L; sulfate, 250 mg/L; iron, 300 µg/L; manganese, 50 µg/L.

[3/]Calculated values.

[4/]Maximum contaminant level (MCL) for drinking water (U.S. Environmental Protection Agency, 2000a): nitrate, 10 mg/L.

pH		Specific conductance		Temperature		Hardness[3/], mg/L $CaCO_3$	Calcium, dissolved, mg/L as Ca	Magnesium, dissolved, mg/L, as Mg	Potassium, dissolved, mg/L as K
Field[2/]	Lab	Lab µS/cm	Field µS/cm	Air, °C	Water, °C				
00400	00403	90095	00095	00020	00010	00900	00915	00925	00935
4.3	—	—	99	—	24.7	14	2.3	2.0	2.3
4.3	—	—	110	—	23.8	23	3.7	3.3	.6
4.5	—	—	141	16.5	19.0	20	2.9	3.2	2.4
5.3	—	—	179	31.0	21.1	23	3.6	3.5	.6
5.4	—	—	208	—	23.1	31	5.4	4.3	1.7
5.5	—	—	215	17.0	18.1	28	4.2	4.4	1.1
5.8	E 6.7	239	240	23.0	19.4	33	4.9	5.0	2.8
7.0	—	—	295	26.0	30.2	65	15.2	6.5	1.8
6.8	—	—	12,300	—	25.4	1,900	132	389	91.1
7.4	—	—	2,280	—	17.3	240	25.0	44.0	13.2
7.3	E 7.9	449	466	21.5	21.5	97	19	12	3.8
5.9	E 6.6	305	308	—	17.1	19	2.6	3.0	19
6.4	—	—	647	—	23.2	250	85.0	8.7	.7
7.0	—	—	370	18.0	19.9	150	51.9	4.4	1.0
7.3	—	—	640	—	26.7	170	52.5	8.3	2.3
6.9	—	—	628	—	24.4	250	78.6	12.4	.8
7.3	—	—	1,040	13.2	10.8	320	71.8	33.2	9.2
6.9	E 8.1	995	986	21.0	14.3	320	100	16	2.7
7.5	—	—	710	26.5	24.2	210	59.1	14.9	2.4
6.9	—	—	12,000	—	25.6	1,600	150	294	77.8
7.8	—	—	1,710	18.0	16.8	290	84.7	18.1	4.9
6.8	E 8.5	794	795	—	21.2	260	71	20	3.0
8.0	—	—	56,000	17.5	24.2	7,500	510	1,500	448
6.3	—	—	33,300	—	—	3,700	253	733	226
7.6	—	—	43,100	9.5	13.8	4,900	297	1,000	277
8.0	E 7.9	36,700	37,600	23.0	28.4	4,100	270	833	260

Appendix A. Surface-water-quality data, Cumberland Island, April 1999 through March 2000—Continued

[—, data not collected; do., ditto; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; ° C, degrees Celsius; mm, millimeter; E, estimated; <, less than; >, greater than; M, presence of material verified, but not quantified; As, arsenic; ANC, acid neutralizing capacity; Br, bromide; $CaCO_3$, calcium carbonate; Ca, calcium; Cd, cadmium; Cl, chloride; Cr, chromium; Cu, copper; Fe, iron; F, fluoride; HCO_3, bicarbonate; Hg, mercury; K, potassium; Mg, magnesium; Mn, manganese; N, nitrogen; Na, sodium; Ni, nickel; NTU, nephelometric turbidity units; P, phosphorus; Pb, lead; SiO_2, silica dioxide; SO_4, sulfate; Zn, zinc; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, exceeds U.S. Environmental Protection Agency secondary standards for drinking water; darker shading, exceeds U.S. Environmental Protection Agency maximum contaminant level (MCL) for drinking water; all data in this appendix are available online at *http://waterdata.usgs.gov/ga/nwis*]

Location number (fig. 1)	Site name	Date	Sodium, Dissolved, mg/L as Na	Sodium, Percent[3/]	ANC, unfiltered, lab, mg/L as $CaCO_3$	Alkalinity, Dissolved, laboratory, mg/L as $CaCO_3$	Alkalinity, Field, mg/L as $CaCO_3$	Bicarbonate, dissolved, field, mg/L as HCO_3	Bromide, dissolved, mg/L as Br	Chloride[2/], dissolved, mg/L as Cl
			00930	00932	90410	29803	39086	00453	71870	00940
2	North Cut Pond 2A	04-27-99	7.9	51	—	—	—	—	0.02	10.2
2	do.	10-05-99	9.4	47	—	—	—	—	.03	10.3
2	do.	12-14-99	13.0	55	—	—	—	—	<.20	22.4
4	Whitney Lake	04-27-99	23.0	67	—	6.7	—	—	.14	37.4
4	do.	10-06-99	28.6	65	—	—	—	—	.16	50.2
4	do.	12-14-99	26.6	66	—	—	—	—	.20	50.0
4	do.	03-08-00	33	66	12	—	—	—	—	56
6	Whitney outflow	04-27-99	25.8	46	—	41	40	49	.12	46.6
6	do.	10-05-99	1,900	67	—	—	—	—	14.0	4,400
6	do.	12-15-99	380	76	—	—	—	—	4.00	620
6	do.	03-07-00	54	54	70	—	—	—	—	78
11	Willow Pond	03-08-00	42	68	14	—	—	—	—	71
12	Lake Retta complex at foot bridge on Willow Pond Trail	10-06-99	56.1	33	—	—	—	—	.45	112
13	Lake Retta complex 420 feet south of foot bridge	04-29-99	17.8	21	—	120	123	150	.14	31.7
15	Lake Retta	04-28-99	44.7	37	—	68	66	81	.05	82.0
15	do.	10-06-99	51.8	31	—	—	—	—	.25	95.0
15	do.	12-15-99	178	54	—	—	—	—	2.00	369
15	do.	03-07-00	87	37	159	—	—	—	—	170
17	Lake Retta outflow	04-28-99	54.4	36	—	180	223	272	.35	83.2
17	do.	10-05-99	E 1,840	—	—	—	—	—	12.0	3,720
17	do.	12-15-99	78.4	37	—	—	—	—	<1.00	169
17	do.	03-07-00	73	38	221	—	—	—	—	120
25	South End Pond 3	04-27-99	12,300	77	—	120	77	94	75.0	21,800
25	do.	10-06-99	6,300	78	—	—	—	—	70.0	11,200
25	do.	12-16-99	9,720	80	—	—	—	—	200	15,500
25	do.	03-06-00	7,200	78	95	—	—	—	—	13,000

[1/]Agency analyzing sample: 1028, U.S. Geological Survey, Georgia District Laboratory; 81213, U.S. Geological Survey, Ocala, Florida Laboratory.

[2/]Secondary standards for drinking water (U.S. Environmental Protection Agency, 2000b): total dissolved solids, 500 mg/L; pH, 6.5 to 8.5; chloride, 250 mg/L; fluoride, 2 mg/L; sulfate, 250 mg/L; iron, 300 µg/L; manganese, 50 µg/L.

[3/]Calculated values.

[4/]Maximum contaminant level (MCL) for drinking water (U.S. Environmental Protection Agency, 2000a): nitrate, 10 mg/L.

Fluoride[2/], dissolved, mg/L as F	Silica, dissolved, mg/L as SiO_2	Sulfate[2/], dissolved, mg/L as SO_4	Solids[1/]		Ammonia, dissolved, mg/L as N	Nitrate[4/], dissolved, mg/L as N	Orthophosphorus, dissolved, mg/L, as P	Arsenic, total, µg/L as As	Cadmium, total, µg/L as Cd	Chromium, total recoverable, µg/L as Cr	Copper, total recoverable, µg/L as Cu
			Residue at 180° C, dissolved, mg/L	Sum of constituents, dissolved[2/], mg/L							
00950	**00955**	**00945**	**70300**	**70301**	**00608**	**00618**	**00671**	**01002**	**01027**	**01034**	**01042**
0.1	0.9	16.7	—	—	0.013	<0.02	<0.020	—	—	—	—
M	3.7	23.2	—	—	—	<.02	.013	<2	<0.5	1.4	<1
<.2	.5	23.7	—	—	—	.20	<.200	—	—	—	—
.3	.7	1.7	—	75	.042	.04	.111	—	—	—	—
.3	2.4	3.4	—	—	—	<.02	.104	<2	<.5	<1	<1
.3	3.3	7.8	—	—	—	<.20	.065	—	—	—	—
.3	2.2	7.1	184	119	—	—	—	4	<.5	<1	<1
.7	2.0	9.1	—	132	.017	<.02	<.020	—	—	—	—
<.02	4.5	571	—	—	—	<.02	1.30	<10	<10	<10	<10
—	2.8	126	—	—	—	12.0	—	—	—	—	—
1.1	1.2	23	263	234	—	—	—	8	<.5	2	<1
<.1	.1	6.4	242	153	—	—	—	<2	<.5	<1	<1
1.1	11.8	10.6	—	—	—	<.02	.310	15	<.5	5	2.4
.7	4.4	2.9	—	189	.013	.04	.059	—	—	—	—
1.6	2.5	45.2	—	280	.019	.10	.082	—	—	—	—
1.0	15.3	34.8	—	—	—	<.02	.391	9	<.5	1.6	<1
2.0	7.3	63.0	—	—	—	2.0	<.200	—	—	—	—
1.3	.1	69	694	542	—	—	—	6	<.5	<1	<1
1.8	7.5	15.5	—	374	.045	.10	.082	—	—	—	—
2.0	8.4	412	—	—	—	<.02	1.63	<10	<10	<10	<10
1.5	8.6	32.5	—	—	—	1.00	.489	—	—	—	—
1.3	11.0	14	519	446	—	—	—	10	<.5	1.1	<1
5.0	.2	3,030	—	39,700	.825	<.02	<.02	—	—	—	—
<.02	1.5	1,540	—	—	—	<.02	32.6	<10	<10	<10	<10
—	1.4	2,240	—	—	—	—	—	—	—	—	—
.5	1.4	3.7	24,700	21,600	—	—	—	<10	<10	<10	<10

Appendix A. Surface-water-quality data, Cumberland Island, April 1999 through March 2000—Continued

[—, data not collected; do., ditto; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; ° C, degrees Celsius; mm, millimeter; E, estimated; <, less than; >, greater than; M, presence of material verified, but not quantified; As, arsenic; ANC, acid neutralizing capacity; Br, bromide; $CaCO_3$, calcium carbonate; Ca, calcium; Cd, cadmium; Cl, chloride; Cr, chromium; Cu, copper; Fe, iron; F, fluoride; HCO_3, bicarbonate; Hg, mercury; K, potassium; Mg, magnesium; Mn, manganese; N, nitrogen; Na, sodium; Ni, nickel; NTU, nephelometric turbidity units; P, phosphorus; Pb, lead; SiO_2, silica dioxide; SO_4, sulfate; Zn, zinc; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, exceeds U.S. Environmental Protection Agency secondary standards for drinking water; darker shading, exceeds U.S. Environmental Protection Agency maximum contaminant level (MCL) for drinking water; all data in this appendix are available online at *http://waterdata.usgs.gov/ga/nwis*]

Location number (fig. 1)	Site name	Date	Iron[2/], dissolved, µg/L as Fe	Lead, total recoverable, µg/L as Pb	Manganese[2/], dissolved, µg/L as Mn	Mercury, total recoverable, µg/L as Hg	Nickel, total recoverable, µg/L as Ni	Zinc, total recoverable, µg/L as Zn	Tannin and lignin, mg/L
			01046	01051	01056	71900	01067	01092	32240
2	North Cut Pond 2A	04-27-99	—	—	—	—	—	—	5.0
2	do.	10-05-99	—	<1	—	—	<1	17	4.3
2	do.	12-14-99	—	—	—	—	—	—	5.0
4	Whitney Lake	04-27-99	—	—	—	—	—	—	8.5
4	do.	10-06-99	—	<1		—	<1	3.3	6.4
4	do.	12-14-99	—	—	—	—	—	—	5.3
4	do.	03-08-00	760	<1	44	<.1	<1	5.5	7.8
6	Whitney outflow	04-27-99	—	—	—	—	—	—	3.2
6	do.	10-05-99	—	<10	—	—	<10	<10	6.4
6	do.	12-15-99	—	—	—	—	—	—	2.1
6	do.	03-07-00	100	<1	12	<.1	1	3.3	2.5
11	Willow Pond	03-08-00	310	<1	34	<.1	<1	2.6	14
12	Lake Retta complex at foot bridge on Willow Pond Trail	10-06-99	—	2.6	—	—	3.4	12	>9.0
13	Lake Retta complex 420 feet south of foot bridge	04-29-99	—	—	—	—	—	—	3.8
15	Lake Retta	04-28-99	—	—	—	—	—	—	3.8
15	do.	10-06-99	—	<1	—	—	1.3	7.9	8.0
15	do.	12-15-99	—	—	—	—	—	—	6.3
15	do.	03-07-00	130	<1	36	<.1	<1	3.3	4.0
17	Lake Retta outflow	04-28-99	—	—	—	—	—	—	3.0
17	do.	10-05-99	—	<10	—	—	<10	<10	>9.0
17	do.	12-15-99	—	—	—	—	—	—	4.9
17	do.	03-07-00	170	<1	19	<.1	1.1	2.3	3.4
25	South End Pond 3	04-27-99	—	—	—	—	—	—	>9.0
25	do.	10-06-99	—	<10	—	—	<10	85	9.9
25	do.	12-16-99	—	—	—	—	—	—	—
25	do.	03-06-00	40	<10	51	<.1	<10	25	14

[1/]Agency analyzing sample: 1028, U.S. Geological Survey, Georgia District Laboratory; 81213, U.S. Geological Survey, Ocala, Florida Laboratory.

[2/]Secondary standards for drinking water (U.S. Environmental Protection Agency, 2000b): total dissolved solids, 500 mg/L; pH, 6.5 to 8.5; chloride, 250 mg/L; fluoride, 2 mg/L; sulfate, 250 mg/L; iron, 300µg/L; manganese, 50 µg/L.

[3/]Calculated values.

[4/]Maximum contaminant level (MCL) for drinking water (U.S. Environmental Protection Agency, 2000a): nitrate, 10 mg/L.

APPENDIX B.—ENTEROCOCCI CONCENTRATIONS OF THE NEAR-SHORE ATLANTIC OCEAN, CUMBERLAND ISLAND, APRIL 26–30, 1999

Appendix B. Enterococci concentrations of the near-shore Atlantic Ocean, Cumberland Island, April 26–30, 1999

[do., ditto; E, estimated; <, less than; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; all data in this appendix are available online at *http://waterdata.usgs.gov/ga/nwis*]

Location number (fig. 1)	Site identification number	Site name	Date	Time	Enterococci, colonies per 100 milliliters	Sampling depth, feet
					31649	00003
3	305436081241701	North Cut Road Beach	04-27-99	1530	E 8	1.5
3	do.	do.	04-27-99	1535	E 20	3.0
3	do.	do.	04-28-99	1635	E 3	1.5
3	do.	do.	04-28-99	1640	E 8	3.0
3	do.	do.	04-29-99	1155	E 11	1.5
3	do.	do,	04-29-99	1200	E 16	3.0
3	do.	do.	04-30-99	0930	E 4	1.5
3	do.	do,	04-30-99	0935	E 7	3.0
8	305313081244901	South Cut Trail Beach	04-26-99	1600	E 2	1.5
8	do.	do.	04-26-99	1605	37	3.0
8	do.	do.	04-27-99	1600	E 3	1.5
8	do.	do.	04-27-99	1605	E 3	3.0
8	do.	do.	04-28-99	1645	21	1.5
8	do.	do.	04-28-99	1650	E 3	3.0
8	do.	do.	04-29-99	1205	29	1.5
8	do.	do.	04-29-99	1210	25	3.0
8	do.	do.	04-30-99	0940	<1	1.5
8	do.	do.	04-30-99	0945	E 8	3.0
18	304823081265401	Stafford Beach	04-26-99	1635	E 4	1.5
18	do.	do.	04-26-99	1640	E 9	3.0
18	do.	do.	04-27-99	1630	E 8	1.5
18	do.	do.	04-27-99	1635	E 10	3.0
18	do.	do.	04-28-99	1700	E 7	1.5
18	do.	do.	04-28-99	1705	E 1	3.0
18	do.	do.	04-29-99	1230	24	1.5
18	do.	do.	04-29-99	1235	31	3.0
18	do.	do.	04-30-99	0950	<1	1.5
18	do.	do.	04-30-99	0955	<1	3.0
21	304551081273501	Sea Camp Beach	04-26-99	1650	<1	3.0
21	do.	do.	04-27-99	1645	E 1	1.5
21	do.	do.	04-27-99	1650	E 7	3.0
21	do.	do.	04-28-99	1705	E 6	1.5
21	do.	do.	04-28-99	1710	E 6	3.0
21	do.	do.	04-29-99	1240	E 26	1.5
21	do.	do.	04-29-99	1245	57	3.0
21	do.	do.	04-30-99	1000	E 3	1.5
21	do.	do.	04-30-99	1005	E 1	3.0
24	304443081273101	Dungeness Beach	04-26-99	1705	E 1	1.5
24	do.	do.	04-26-99	1710	E 5	3.0
24	do.	do.	04-27-99	1715	<1	3.0
24	do.	do.	04-28-99	1715	E 16	1.5
24	do.	do.	04-28-99	1720	E 6	3.0
24	do.	do.	04-29-99	1245	27	1.5
24	do.	do.	04-29-99	1250	43	3.0
24	do.	do.	04-30-99	1010	<1	1.5
24	do.	do.	04-30-99	1015	E 1	3.0

APPENDIX C.—GROUND-WATER-QUALITY DATA, CUMBERLAND ISLAND, APRIL 1999 AND MARCH 2000

Appendix C. Ground-water-quality data, Cumberland Island, April 1999 and March 2000

[—, data not collected; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; ° C, degrees Celsius; E, estimated; M, presence of material verified, but not quantified; mm, millimeter; ANC, acid neutralizing capacity; As, arsenic; Br, bromide; Ca, calcium; $CaCO_3$, calcium carbonate; Cd, cadmium; Cl, chloride; Cr, chromium; Cu, Copper; F, fluoride; Fe, iron; HCO_3, bicarbonate; Hg, mercury; K, potassium; Mg, magnesium; Mn, manganese; N, nitrogen; Na, sodium; Ni, nickel; P, phosphorus; Pb, lead; SiO_2, silica dioxide; SO_4, sulfate; Zn, zinc; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, exceeds U.S. Environmental Protection Agency secondary standards for drinking water; all data in this appendix are available online at *http://waterdata/usgs/gov/ga.nwis*]

Location number (fig. 1)	Site identification number	Site name	Other well identifier	Date	Time	Well depth, feet	Agency analyzing sample[1]	Barometric pressure, mm of Hg	Dissolved oxygen, mg/L	pH		Specific conductance		Temperature, water, °C
										Field[2]	Laboratory	Laboratory µS/cm	Field, µS/cm	
						72008	00028	00025	00300	00400	00403	90095	00095	00010
Surficial aquifer (unconfined and confined water-bearing zones)														
5	305320081244601	34F017	WS01Whitney outflow NE	03-07-00	1100	1	81213	773	<0.5	6.3	E 7.3	297	311	17.9
7	305314081250301	34F018	WS03 Whitney outflow SW	03-08-00	1200	1	81213	773	<.5	5.6	E 7.0	361	373	17.3
14	304953081261001	34E016	RH01 Lake Retta	03-07-00	1400	1	81213	773	.5	6.6	E 7.8	881	917	17.3
16	304940081261101	34E017	RH02 Lake Retta outflow	03-07-00	1500	1	81213	773	.7	7.2	E 8.0	1,640	1,670	16.9
22	304450081280002	34D014	KBMP 8; Site 3	03-07-00	0900	30	81213	773	<.5	5.9	E 7.6	750	691	20.2
23	304450081280004	34D016	KBMP 10; Site 3	03-08-00	1400	132.4	81213	773	<.5	7.5	E 8.2	395	412	21.1
26	304311081281302	34D008	KBMP 2; Site 1	03-06-00	1630	23	81213	771	.6	7.5	E 8.2	3,150	—	22.2
27	304311081281303	34D009	KBMP 3; Site 1	03-06-00	1600	94	81213	771	<.5	6.9	E 7.9	23,300	—	22.3
28	304310081272602	34D011	KBMP 5; Site 2	03-06-00	1400	44	81213	771	<.5	7.3	E 8.0	21,300	>10,000	21.4
29	304310081272603	34D012	KBMP 6; Site 2	03-06-00	1430	71	81213	771	<.5	7.1	E 7.8	44,800	>10,000	21.4
Upper Floridan aquifer (confined multiple water-bearing zones)														
1	[6]	34F015	Candler at water tower	04-27-99	1300	—	1028	760	<.5	7.4	—	—	627	27.0
9	[6]	34E002	Plum Orchard #2 (east well)	04-28-99	0930	600	1028	760	<.5	7.0	—	—	348	22.8
10	[6]	34E012	Reddick	04-28-99	1030	—	1028	760	<.5	6.9	—	—	372	22.5
19	[6]	34E003	Cumberland Island Greyfield 02	04-28-99	1100	730	1028	760	<.5	7.5	—	—	89	27.1
20	[6]	34E010	Cumberland Island 32, Rockefeller	04-27-99	1100	750	1028	760	<.5	7.3	—	—	574	24.0

[1]Agency analyzing sample: 1028, U.S. Geological Survey, Georgia District Laboratory; 81213, U.S. Geological Survey, Ocala, Florida Laboratory.
[2]Secondary standards for drinking water (U.S. Environmental Protection Agency, 2000b): total dissolved solids, 500 mg/L; pH, 6.5 to 8.5; chloride, 250 mg/L; sulfate, 250 mg/L; iron, 300 µg/L; manganese, 50 µg/L.
[3]Calculated values.
[4]Sampler type code: 4010, flowing well; 4040, submersible positive-pressure pump; 4080, peristaltic pump.
[5]Sampling condition: 4, flowing well; 8, pumping.
[6]Available online at *http://waterdata.usgs.gov/ga.nwis*.
[7]On April 27, 1999, the submersible pump in this well was not turned on. Therefore, water sampled came in contact with the pump, but was not aerated by the pump.

Appendix C. Ground-water-quality data, Cumberland Island, April 1999 and March 2000—Continued

[—, data not collected; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; E, estimated; M, presence of material verified, but not quantified; mm, millimeter; ANC, acid neutralizing capacity; As, arsenic; Br, bromide; Ca, calcium; $CaCO_3$, calcium carbonate; Cd, cadmium; Cl, chloride; Cr, chromium; Cu, Copper; F, fluoride; Fe, iron; HCO_3, bicarbonate; Hg, mercury; K, potassium; Mg, magnesium; Mn, manganese; N, nitrogen; Na, sodium; Ni, nickel; P, phosphorus; Pb, lead; SiO_2, silica dioxide; SO_4, sulfate; Zn, zinc; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, exceeds U.S. Environmental Protection Agency secondary standards for drinking water; all data in this appendix are available online at *http://waterdata/usgs/gov/ga.nwis*]

Location number (fig. 1)	Other well identifier	Hardness[3/], mg/L $CaCO_3$	Calcium, dissolved, mg/L as Ca	Magnesium, dissolved, mg/L as Mg	Potassium, dissolved, mg/L as K	Sodium, dissolved, mg/L as Na	ANC: Unfiltered, fixed 4.5, laboratory, mg/L as $CaCO_3$	ANC: Dissolved, Gran titration, laboratory, mg/L as $CaCO_3$	Alkalinity, field, mg/L as $CaCO_3$	Bicarbonate, dissolved, field, mg/L as HCO_3	Bromide, dissolved, mg/L as Br	Chloride[2/] dissolved, mg/L as Cl
		00900	00915	00925	00935	00930	90410	29803	39086	00453	71870	00940
	Surficial aquifer (unconfined and confined water-bearing zones)											
5	WS01Whitney outflow NE	68	9.1	11	3.8	31	39	—	—	—	—	62
7	WS03 Whitney outflow SW	52	9.3	7.0	5.2	39	38	—	—	—	—	60
14	RH01 Lake Retta	280	93	12	2.0	75	137	—	—	—	—	170
16	RH02 Lake Retta outflow	270	76	20	9.8	270	329	—	—	—	—	320
22	KBMP 8; Site 3	210	66	11	3.3	70	122	—	—	—	—	120
23	KBMP 10; Site 3	190	66	5.7	1.8	14	174	—	—	—	—	21
26	KBMP 2; Site 1	580	150	49	6.0	410	206	—	—	—	—	810
27	KBMP 3; Site 1	2,900	310	519	140	4,300	572	—	—	—	—	8,000
28	KBMP 5; Site 2	2,600	260	468	140	3,900	401	—	—	—	—	6,900
29	KBMP 6, Site2	5,100	390	1,000	300	9,000	223	—	—	—	—	16,000
	Upper Floridan aquifer (confined multiple water-bearing zones)											
1	Candler at water tower	320	72.6	33.5	2.4	26.3	—	160	163	199	0.15	35.3
9	Plum Orchard #2 (east well)	28	4.1	4.3	1.7	21.9	—	29	—	—	.14	30.7
10	Reddick	320	70.8	33.6	2.3	25.0	—	160	—	—	.14	35.1
19	Cumberland Island Greyfield 02	150	50.9	6.0	1.1	16.3	—	120	—	—	.14	36.7
20	Cumberland Island 32, Rockefeller	340	77.0	36.8	2.3	23.1	—	160	216	264	<.02	31.7

[1/]Agency analyzing sample: 1028, U.S. Geological Survey, Georgia District Laboratory; 81213, U.S. Geological Survey, Ocala, Florida Laboratory.

[2/]Secondary standards for drinking water (U.S. Environmental Protection Agency, 2000b): total dissolved solids, 500 mg/L; pH, 6.5 to 8.5; chloride, 250 mg/L; sulfate, 250 mg/L; iron, 300 µg/L; manganese, 50 µg/L.

[3/]Calculated values.

[4/]Sampler type code: 4010, flowing well; 4040, submersible positive-pressure pump; 4080, peristaltic pump.

[5/]Sampling condition: 4, flowing well; 8, pumping.

[6/]Available online at *http://waterdata.usgs.gov/ga/nwis*.

[7/]On April 27, 1999, the submersible pump in this well was not turned on. Therefore, water sampled came in contact with the pump, but was not aerated by the pump.

Appendix C. Ground-water-quality data, Cumberland Island, April 1999 and March 2000—Continued

[—, data not collected; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; E, estimated; M, presence of material verified, but not quantified; mm, millimeter; ANC, acid neutralizing capacity; As, arsenic; Br, bromide; Ca, calcium; $CaCO_3$, calcium carbonate; Cd, cadmium; Cl, chloride; Cr, chromium; Cu, Copper; F, fluoride; Fe, iron; HCO_3, bicarbonate; Hg, mercury; K, potassium; Mg, magnesium; Mn, manganese; N, nitrogen; Na, sodium; Ni, nickel; P, phosphorus; Pb, lead; SiO_2, silica dioxide; SO_4, sulfate; Zn, zinc; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, exceeds U.S. Environmental Protection Agency secondary standards for drinking water; all data in this appendix are available online at *http://waterdata/usgs/gov/ga.nwis*]

Location number (fig. 1)	Other well identifier	Fluoride, dissolved, mg/L as F	Silica, dissolved, mg/L as SiO_2	Sulfate[2/], dissolved, mg/L as SO_4	Solids[2/] Residue at 180° C, dissolved, mg/L	Solids[2/] Sum of constituents[3/], dissolved, mg/L	Ammonia, dissolved, mg/L as N	Nitrate, dissolved, mg/L as N	Ortho-phosphorus, dissolved, mg/L, as P	Fecal coliform, colonies per 100 milliliters	Arsenic, total, µg/L as As	Cadmium, total, µg/L as Cd
		00950	00955	00945	70300	70301	00608	00618	00671	31625	01002	01027
	Surficial aquifer (unconfined and confined water-bearing zones)											
5	WS01Whitney outflow NE	0.5	13	5.4	171	160	—	—	—	—	<2	<0.5
7	WS03 Whitney outflow SW	.5	21	27	251	194	—	—	—	—	<2	<.5
14	RH01 Lake Retta	1.4	26	46	647	508	—	—	—	—	26	<.5
16	RH02 Lake Retta outflow	1.7	18	19	1,090	938	—	—	—	—	19	<.5
22	KBMP 8; Site 3	.1	7.9	66	465	418	—	—	—	—	<2	<.5
23	KBMP 10; Site 3	.4	36	3.0	260	252	—	—	—	—	<2	<.5
26	KBMP 2; Site 1	.3	21	94	1,820	1,660	—	—	—	—	<2	<.5
27	KBMP 3; Site 1	.2	51	860	14,900	14,500	—	—	—	—	<2	<.5
28	KBMP 5; Site 2	.4	36	910	13,600	12,900	—	—	—	—	<5	<5
29	KBMP 6; Site2	<.1	11	<0.2	30,900	—	—	—	—	—	<5	<5
	Upper Floridan aquifer (confined multiple water-bearing zones)											
1	Candler at water tower	.7	16.1	136	—	422	0.194	0.100	<0.020	<1	<2	<.5
9	Plum Orchard #2 (east well)	.7	.2	.4	—	82	.172	<.020	<.020	—	<2	<.5
10	Reddick	.6	13.6	148	—	423	.205	.020	<.020	—	<2	<.5
19	Cumberland Island Greyfield 02	.3	9.7	20.4	—	216	.239	<.020	.013	—	<2	<.5
20	Cumberland Island 32, Rockefeller	.5	13.2	152	—	467	.233	.040	<.020	<1	<2	<.5

[1/]Agency analyzing sample: 1028, U.S. Geological Survey, Georgia District Laboratory; 81213, U.S. Geological Survey, Ocala, Florida Laboratory.

[2/]Secondary standards for drinking water (U.S. Environmental Protection Agency, 2000b): total dissolved solids, 500 mg/L; pH, 6.5 to 8.5; chloride, 250 mg/L; sulfate, 250 mg/L; iron, 300 µg/L; manganese, 50 µg/L.

[3/]Calculated values.

[4/]Sampler type code: 4010, flowing well; 4040, submersible positive-pressure pump; 4080, peristaltic pump.

[5/]Sampling condition: 4, flowing well; 8, pumping.

[6/]Available online at *http://waterdata.usgs.gov.ga.nwis*.

[7/]On April 27, 1999, the submersible pump in this well was not turned on. Therefore, water sampled came in contact with the pump, but was not aerated by the pump.

Appendix C. Ground-water-quality data, Cumberland Island, April 1999 and March 2000—Continued

[—, data not collected; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; E, estimated; M, presence of material verified, but not quantified; mm, millimeter; ANC, acid neutralizing capacity; As, arsenic; Br, bromide; Ca, calcium; $CaCO_3$, calcium carbonate; Cd, cadmium; Cl, chloride; Cr, chromium; Cu, Copper; F, fluoride; Fe, iron; HCO_3, bicarbonate; Hg, mercury; K, potassium; Mg, magnesium; Mn, manganese; N, nitrogen; Na, sodium; Ni, nickel; P, phosphorus; Pb, lead; SiO_2, silica dioxide; SO_4, sulfate; Zn, zinc; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, exceeds U.S. Environmental Protection Agency secondary standards for drinking water; all data in this appendix are available online at *http://waterdata/usgs/gov/ga.nwis*]

Location number (fig. 1)	Other well identifier	Chromium, total recover-able, µg/L as Cr	Copper, total recoverable, µg/L as Cu	Iron[2/], dissolved, µg/L as Fe	Lead, total recoverable, µg/L as Pb	Manganese[2/], dissolved, µg/L as Mn	Nickel, total recoverable, µg/L as Ni	Zinc, total recoverable, µg/L as Zn	Sampler type code[4/]	Sampling condition[5/]
		01034	01042	01046	01051	01056	01067	01092	84164	72006
	Surficial aquifer (unconfined and confined water-bearing zones)									
5	WS01Whitney outflow NE	1.1	<1	720	<1	27	<1	1.5	4080	—
7	WS03 Whitney outflow SW	6.4	<1	2,100	4.1	41	<1	3.1	4080	—
14	RH01 Lake Retta	1.1	<1	210	1.2	660	<1	6.7	4080	—
16	RH02 Lake Retta outflow	3.9	<1	6,200	<1	300	<1	1.7	4080	—
22	KBMP 8; Site 3	2.5	14	70	3.5	44	1.4	8.3	4040	—
23	KBMP 10; Site 3	1.4	5.6	70	3.2	8.4	1.1	4.6	4040	—
26	KBMP 2; Site 1	4.8	79	M	7.9	76	2.9	25	4040	—
27	KBMP 3; Site 1	1.9	<1	20	<1	120	2.2	4.5	4040	—
28	KBMP 5; Site 2	<5	<5	M	<5	62	<5	23	4040	—
29	KBMP 6, Site2	<5	<5	M	<5	290	<5	77	4040	—
	Upper Floridan aquifer (confined multiple water-bearing zones)									
1	Candler at water tower	<1	<1	—	<1	—	<1	2.0	4040	—
9	Plum Orchard #2 (east well)	<1	<1	—	<1	—	<1	4.7	4040	8
10	Reddick	<1	<1	—	<1	—	<1	26	4040	—
19	Cumberland Island Greyfield 02	<1	<1	—	<1	—	<1	14	4010	4
20	Cumberland Island 32, Rockefeller	<1	<1	—	<1	—	<1	6.8	[7/]4040	4

[1/]Agency analyzing sample: 1028, U.S. Geological Survey, Georgia District Laboratory; 81213, U.S. Geological Survey, Ocala, Florida Laboratory.
[2/]Secondary standards for drinking water (U.S. Environmental Protection Agency, 2000b): total dissolved solids, 500 mg/L; pH, 6.5 to 8.5; chloride, 250 mg/L; sulfate, 250 mg/L; iron, 300 µg/L; manganese, 50 µg/L.
[3/]Calculated values.
[4/]Sampler type code: 4010, flowing well; 4040, submersible positive-pressure pump; 4080, peristaltic pump.
[5/]Sampling condition: 4, flowing well; 8, pumping.
[6/]Available online at *http://waterdata.usgs.gov/ga/nwis*.
[7/]On April 27, 1999, the submersible pump in this well was not turned on. Therefore, water sampled came in contact with the pump, but was not aerated by the pump.

APPENDIX D.—GROUND-WATER-QUALITY DATA FOR WELLS SCREENED IN THE SURFICIAL AQUIFER, SOUTHERN END OF CUMBERLAND ISLAND, 1989

Appendix D. Ground-water-quality data for wells screened in the surficial aquifer, southern end of Cumberland Island, 1989

[Data sources: Wilson, 1990, p. 35, and U.S. Geological Survey water-quality data base; do., ditto; —, data not collected; E, estimated; KBMP, Kings Bay Monitoring Project; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; ANC, acid neutralizing capacity; Ca, calcium; $CaCO_3$, calcium carbonate; Cl, chloride; F, fluoride; HCO_3, bicarbonate; K, potassium; Mg, magnesium; Na, sodium; S, sulfur; SiO_2, silica dioxide; SO_4, sulfate, Sr, strontium; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, exceeds U.S. Environmental Protection Agency secondary standards for drinking water; all data in this appendix are available online at *http://waterdata/usgs.gov/ga/nwis*]

Location number (fig. 1)	Site identification number	Site name	Other well identifier	Depth of well, feet	Date	Agency analyzing sample[1/]	Agency collecting sample[2/]	Dissolved oxygen, mg/L	pH		Specific conductance	
									Field[3/]	Laboratory	Laboratory, µS/cm	Field, µS/cm
						00028	00027	00300	00400	00403	90095	00095
A	304451081280101	34D006	KBMP 11	95	12-12-89	81213	1028	1.8	—	7.7	3,790	4,000
22	304450081280002	34D014	KBMP 8; Site 3	30	12-07-89	81213	1028	3.3	—	6.6	706	700
B	304450081280003	34D015	KBMP 9; Site 3	72	12-12-89	81213	1028	4.0	—	7.6	533	525
C	304450081280001	34D013	KBMP 7; Site 3	89	12-08-89	81213	1028	2.6	—	7.6	2,440	2,500
C	do.	do.	do.	89	12-10-89	81213	1028	—	—	7.4	3,020	3,200
23	304450081280004	34D016	KBMP 10; Site 3	132.4	12-12-89	81213	1028	2.0	—	7.9	547	550
26	304311081281302	34D008	KBMP 2; Site 1	23	07-12-89	81213	1028	1.9	8.0	E 7.5	E 911	820
26	do.	do.	do.	23	12-10-89	81213	1028	4.5	—	8.0	748	760
27	304311081281303	34D009	KBMP 3; Site 1	94	12-11-89	81213	1028	<.5	—	7.0	36,800	36,600
D	304311081281301	34D007	KBMP 1; Site 1	146	12-11-89	81213	1028	<.5	—	7.4	18,400	17,500
28	304310081272602	34D011	KBMP 5; Site 2	44	12-11-89	81213	1028	<.5	—	8.1	2,450	2,750
29	304310081272603	34D012	KBMP 6; Site 2	71	06-22-89	81213	1028	1.9	7.2	E 7.7	E 45,200	20,000
29	do.	do.	do.	7881	12-11-89	81213	1028	2.0	—	7.4	46,200	46,000
E	304310081272601	34D010	KBMP 4; Site 2	94	06-18-89	81213	1028	6.4	7.0	E 7.5	E 36,500	28,500
E	do.	do.	do.	94	12-11-89	81213	1028	4.7	—	7.1	37,900	39,800

[1/]Agency analyzing sample: 81213, U.S. Geological Survey District Water-Quality Laboratory, Ocala, Florida.
[2/]Agency collecting sample: 1028, U.S. Geological Survey.
[3/]Secondary standards for drinking water (U.S. Environmental Protection Agency, 200b); total dissolved solids, 500 mg/L; pH, 6.5 to 8.5; chloride, 250 mg/L; sulfate, 250 mg/L.
[4/]Calculated values.
[5/]Sampler type code: 4030, Suction pump; 4040, Submersible positive-pressure pump.

Appendix D. Ground-water-quality data for wells screened in the surficial aquifer, southern end of Cumberland Island, 1989—Continued

[Data sources: Wilson, 1990, p. 35, and U.S. Geological Survey water-quality data base; do., ditto; —, data not collected; E, estimated; KBMP, Kings Bay Monitoring Project; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ° C, degrees Celsius; ANC, acid neutralizing capacity; Ca, calcium; $CaCO_3$, calcium carbonate; Cl, chloride; F, fluoride; HCO_3, bicarbonate; K, potassium; Mg, magnesium; Na, sodium; S, sulfur; SiO_2, silica dioxide; SO_4, sulfate, Sr, strontium; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, exceeds U.S. Environmental Protection Agency secondary standards for drinking water; all data in this appendix are available online at *http://waterdata/usgs.gov/ga/nwis*]

Location number (fig. 1)	Other well identifier	Depth of well, feet	Date	Temperature, water, ° C	Hardness[4/], mg/L as $CaCO_3$	Calcium, dissolved, mg/L as Ca	Magnesium, dissolved, mg/L as Mg	Potassium, dissolved, mg/L as K	Sodium: Dissolved, mg/L as Na	Sodium: Percent[4/]	ANC, unfiltered: Field, mg/L as $CaCO_3$	ANC, unfiltered: Laboratory mg/L as $CaCO_3$	ANC, unfiltered: Bicarbonate, laboratory, mg/L as HCO_3
				00010	00900	00915	00925	00935	00930	00932	00410	00417	00451
A	KBMP 11	95	12-12-89	21.2	1,400	500	28	4.9	200	24	—	138	169
22	KBMP 8; Site 3	30	12-07-89	20.9	170	51	10	4.9	77	49	—	63	77
B	KBMP 9; Site 3	72	12-12-89	20.9	200	76	2.8	1.6	31	25	—	210	256
C	KBMP 7; Site 3	89	12-08-89	22.8	860	315	17	3.3	125	24	—	178	217
C	do.	89	12-10-89	22.8	1,000	385	21	3.8	160	25	—	158	192
23	KBMP 10; Site 3	132.4	12-12-89	20.9	230	75	10	2.1	25	19	—	209	255
26	KBMP 2; Site 1	23	07-12-89	25.0	57	15	4.8	6.6	180	86	—	218	267
26	do.	23	12-10-89	20.1	290	85	19	5.5	52	28	—	331	403
27	KBMP 3; Site 1	94	12-11-89	22.7	4,800	420	920	260	7,300	75	—	429	523
D	KBMP 1; Site 1	146	12-11-89	22.8	2,700	440	380	92	3,250	72	275	232	283
28	KBMP 5; Site 2	44	12-11-89	21.6	270	24	52	28	385	73	—	261	319
29	KBMP 6; Site 2	71	06-22-89	21.7	5,700	400	1,150	355	9,800	78	268	231	282
29	do.	71	12-11-89	21.8	5,700	400	1,150	385	9,600	77	—	244	297
E	KBMP 4; Site 2	94	06-18-89	23.7	4,700	400	900	255	7,300	76	334	275	336
E	do.	94	12-11-89	22.0	4,900	400	940	280	7,600	76	—	234	285

[1/]Agency analyzing sample: 81213, U.S. Geological Survey District Water-Quality Laboratory, Ocala, Florida.
[2/]Agency collecting sample: 1028, U.S. Geological Survey.
[3/]Secondary standards for drinking water (U.S. Environmental Protection Agency, 2000b): total dissolved solids, 500 mg/L; chloride, 250 mg/L; sulfate, 250 mg/L.
[4/]Calculated values.
[5/]Sampler type code: 4030, Suction pump; 4040, Submersible positive-pressure pump.

Appendix D. Ground-water-quality data for wells screened in the surficial aquifer, southern end of Cumberland Island, 1989—Continued

[Data sources: Wilson, 1990, p. 35, and U.S. Geological Survey water-quality data base; do., ditto; —, data not collected; E, estimated; KBMP, Kings Bay Monitoring Project; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; ANC, acid neutralizing capacity; Ca, calcium; $CaCO_3$, calcium carbonate; Cl, chloride; F, fluoride; HCO_3, bicarbonate; K, potassium; Mg, magnesium; Na, sodium; S, sulfur; SiO_2, silica dioxide; SO_4, sulfate, Sr, strontium; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, exceeds U.S. Environmental Protection Agency secondary standards for drinking water; all data in this appendix are available online at *http://waterdata/usgs.gov/ga/nwis*]

Location number (fig. 1)	Other well identifier	Depth of well, feet	Date	Chloride[3/], dissolved, mg/L as Cl	Fluoride, dissolved, mg/L as F	Silica, dissolved, mg/L as SiO_2	Sulfate[3/], dissolved, mg/L as SO_4	Sulfide, dissolved, mg/L as S	Solids[3/]		Strontium, dissolved, µg/L as Sr	Sampler type code[5/]
									Residue at 180 °C, dissolved, mg/L	Sum of constituents[4/], dissolved, mg/L		
				00940	00950	00955	00945	00746	70300	70301	01080	84164
A	KBMP 11	95	12-12-89	1,050	0.1	53.5	95	.5	2,610	2,010	—	4030
22	KBMP 8; Site 3	30	12-07-89	140	.1	5.7	71	.1	454	398	—	4040
B	KBMP 9; Site 3	72	12-12-89	43	.2	63.6	2.1	.3	382	346	—	—
C	KBMP 7; Site 3	89	12-08-89	604	.2	56.1	60	.2	1,740	1,290	1,500	4040
C	do.	89	12-10-89	796	.2	54.8	78	—	2,210	1,590	—	4040
23	KBMP 10; Site 3	132.4	12-12-89	29	.3	36.2	41	.6	358	345	—	4040
26	KBMP 2; Site 1	23	07-12-89	64	.8	22.0	139	—	564	563	—	—
26	do.	23	12-10-89	40	.3	21.6	18	.2	470	440	—	4040
27	KBMP 3; Site 1	94	12-11-89	13,100	.5	27.8	1,680	56	25,400	24,000	—	4040
D	KBMP 1; Site 1	146	12-11-89	6,200	.5	51.4	648	7.7	12,500	11,200	—	4040
28	KBMP 5; Site 2	44	12-11-89	580	1.2	33.6	62	70	1,350	1,390	—	4040
29	KBMP 6; Site 2	71	06-22-89	17,400	.4	12.0	2,280	—	32,600	31,500	—	—
29	do.	71	12-11-89	17,200	.6	12.8	2,240	.3	33,200	31,100	—	4040
E	KBMP 4; Site 2	94	06-18-89	13,500	.3	25.0	1,680	—	25,600	24,200	—	—
E	do.	94	12-11-89	13,800	.6	26.1	1,710	4.0	26,600	24,900	—	4040

[1/]Agency analyzing sample: 81213, U.S. Geological Survey District Water-Quality Laboratory, Ocala, Florida.
[2/]Agency collecting sample: 1028, U.S. Geological Survey.
[3/]Secondary standards for drinking water (U.S. Environmental Protection Agency, 2000b): total dissolved solids, 500 mg/L; chloride, 250 mg/L; sulfate, 250 mg/L.
[4/]Calculated values.
[5/]Sampler type code: 4030, Suction pump; 4040, Submersible positive-pressure pump.

APPENDIX E.—GROUND-WATER-QUALITY DATA FOR A WELL OPEN TO THE UPPER FLORIDAN AQUIFER, CUMBERLAND ISLAND, 1994–2000

Appendix E. Ground-water-quality data for a well open to the Upper Floridan aquifer, Cumberland Island, 1994–2000

[Data source: William, L. Osburn, St. Johns River Water Management District, written commun., 2000; —, data not collected; E, estimated; do., ditto; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; ° C, degrees Celsius; ANC, acid neutralizing capacity; Ca, calcium; $CaCO_3$, calcium carbonate; Cl, chloride; F, fluoride; Fe, iron; K, potassium; Mg, magnesium; Na, Sodium; SiO_2, silica dioxide; SO_4, sulfate Sr, strontium; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, exceeds U.S. Environmental Protection Agency secondary standards for drinking water; all data in this appendix are available online at *http://usgs.gov/ga/nwis*]

Location number (fig. 1)	Site identification number	Site name	Other well identifier	Date	Agency analyzing sample[1/]	Agency collecting sample[2/]	Specific conductance: Laboratory, µS/cm	Specific conductance: Field, µS/cm	Temperature, water, °C	Calcium, total recoverable, mg/L as Ca	Magnesium, total recoverable, mg/L as Mg
					00028	00027	90095	00095	00010	00916	00927
W	304522081281301	34E001	Cumberland Island 01, GGS TW 3424	05-18-94	81210	1028	676	—	—	68.7	31.4
W	do.	do.	do.	05-16-95	81210	1028	716	370	25.0	69.0	32.8
W	do.	do.	do.	05-06-96	81210	1028	648	—	—	75.0	37.0
W	do.	do.	do.	05-05-97	81210	1028	724	—	—	77.0	35.5
W	do.	do.	do.	09-15-97	81210	1028	724	—	—	69.1	34.0
W	do.	do.	do.	05-11-98	81210	1028	765	E 736	25.0	77.8	39.3
W	do.	do.	do.	10-27-98	81210	1028	727	E 747	24.5	77.7	38.1
W	do.	do.	do.	05-03-99	81210	1028	723	E 738	23.0	77.4	37.1
W	do.	do.	do.	09-27-99	81210	1028	732	E 743	26.5	76.1	36.8
W	do.	do.	do.	05-10-00	81210	1028	679	E 740	25.0	74.7	37.7
W	do.	do.	do.	09-12-00	81210	1028	707	E 731	24.5	73.4	38.5

[1/] Agency analyzing sample: 81210, St. Johns Water Management District, Florida.
[2/] Agency collecting sample: 1028, U.S. Geological Survey.
[3/] Secondary standards for drinking water (U.S. Environmental Protection Agency, 2000b); total dissolved solids, 500 mg/L; iron, 300 µg/L.
[4/] May be an erroneous value.

Appendix E. Ground-water-quality data for a well open to the Upper Floridan aquifer, Cumberland Island, 1994–2000—Continued

[Data source: William, L. Osburn, St. Johns River Water Management District, written commun., 2000; —, data not collected; E, estimated; do., ditto; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; ^{o} C, degrees Celsius; ANC, acid neutralizing capacity; Ca, calcium; $CaCO_3$, calcium carbonate; Cl, chloride; F, fluoride; Fe, iron; K, potassium; Mg, magnesium; Na, Sodium; SiO_2, silica dioxide; SO_4, sulfate Sr, strontium; 5-digit numbers in table heading are U.S. Geological Survey water-quality data base parameter codes; shading, exceeds U.S. Environmental Protection Agency secondary standards for drinking water; all data in this appendix are available online at *http://usgs.gov/ga/nwis*]

Location number (fig. 1)	Other well identifier	Potassium, total recoverable, mg/L as K	Sodium, total recoverable, mg/L as Na	ANC, unfiltered, laboratory, mg/L as $CaCO_3$	Chloride, unfiltered, mg/L as Cl	Fluoride, total, mg/L as F	Silica, total, mg/L as SiO_2	Sulfate, mg/L as SO_4	Solids, residue at 180 ^{o} C, dissolved, mg/L[3/]	Iron[3/], total recoverable, µg/L as Fe	Strontium, total recoverable, µg/L as Sr
		00937	**00929**	**00410**	**99220**	**00951**	**00956**	**00946**	**70300**	**01045**	**01082**
W	Cumberland Island 01, GGS TW 3424	2.1	19.3	162	36	0.5	49	150	505	2,260[4/]	584
W	do.	2.7	21.0	164	36	.6	32	220	538	—	580
W	do.	2.4	23.0	163	34	.6	48	200	488	180	655
W	do.	1.9	21.0	165	32	.6	49	170	504	260	640
W	do.	2.2	21.1	165	33	.6	50	170	E 484	120	578
W	do.	2.2	22.1	165	32	.6	50	170	530	200	672
W	do.	2.0	22.3	162	33	.6	50	170	526	E 40	697
W	do.	2.1	23.0	159	31	.6	50	170	537	E 40	669
W	do.	2.1	23.5	161	34	E .6	50	190	500	120	679
W	do.	2.5	24.8	163	31	.6	35	170	521	90	649
W	do.	2.6	22.4	160	32	.6	47	170	504	E 30	611

[1/]Agency analyzing sample: 81210, St. Johns Water Management District, Florida.
[2/]Agency collecting sample: 1028, U.S. Geological Survey.
[3/]Secondary standards for drinking water (U.S. Environmental Protection Agency, 2000b): total dissolved solids, 500 mg/L; iron, 300 µg/L.
[4/]May be an erroneous value.